

# Spatial and Temporal Pattern of Urban Smart Development in China and Its Driving Mechanism

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**Abstract:** Smart urban development is an inevitable choice, and is essential to overall strength improvement. It is important to explore an urban smart development path which unites smart growth with driving shrinkage perfectly in forming scientific and sustainable development concept and responding to new normal strategic opportunities. Based on statistic data of 294 prefecture-level cities and above in China from 2000 to 2015, we analyzed spatial and temporal evolution of urban smart development in China by constructing a dynamic fitting model of urban land expansion, population growth, and economic development as well as the coefficient of variation of urban smart development (*CVSD*). Further efforts were then made to consider differential distribution regularity of urban smart development so as to understand the driving mechanisms of heterogeneous classification of urban smart development in China from different scales and scale variation. Our results indicate that: 1) the disordered growth tendency of urban cities in China is overall well controlled in the middle, and late research and it mainly presented a doublet coexistence of shrinkage disordered cities and smart developing cities. It is particularly obvious that Northeast China and East China have regarded shrinkage disordered cities and smart developing cities as main development tendency separately. 2) Areas with basic stability and relative variation were relatively dispersed across the time period, but the proportion was far beyond areas with significant variation. It demonstrates a relative equilibrium spatial and temporal differential evolution pattern of prefecture-level cities and above in China, except for Tongling, Lanzhou and Chaoyang. 3) prefecture-level cities and above in China are mostly characterized by shrinkage disordered and smart development classification under the background of different scale and scale variation from 2000–2015; however, the spatial resonance relation is not obvious. 4) There are many interaction factors forming an important driving mechanism in developing the spatial and temporal pattern of urban smart development in China, including natural geographical factors, industrial structure adjustment, human capital radiation, regional traffic accessibility, and government decision-making intervention.

**Keywords:** urban smart development; spatial and temporal differential pattern; driving mechanism; interaction factors; China

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## 1 Introduction

Smart development means a synthetic characterization and positive feedback of good coherent match among resource allocation, spatial pattern, and comprehensive performance, and it is a logic reconstruction of eco-

nomic new normal development based on the perspective of reasonable stock of land and orderly migration of population. Regional cities have rapidly transformed in recent years (Liu et al., 2015). Several cities have developed a pie-style sprawl along with an increasingly prominent contradiction between people and land,

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which in turn hampers healthy and sustainable development of urban economy to some extent (Li et al., 2016; Li et al., 2017). Apart from obvious problems of land expansion with low density, urban shrinkage resulting from population structural changes, industrial structure adjustment and resource depletion, *etc.* have also appeared in several cities (Elzerman and Bontje, 2015; Yang and Dunford, 2017). It has become an important proposition in the discussion of obtaining urban smart development on coordinating a harmonious state of urban growth and shrinkage so as to regulate and guide scientific and healthy development of cities (Hospers and Gert-Jan, 2014; Kamila et al., 2017). It considers the implementation paths to fulfill the reasonable incremental demand, and explores high-efficiency transition patterns from different time-series and cross-sectional shapes, aiming to maximize the comprehensive benefits of urban development (Lucia et al., 2015; Ramaswami et al., 2016).

In order to cope with the spatial growth pattern transformation from high-density expansion of urban fringe to suburban low-density sprawl during the period of industrialization, western scholars are groping for ways to implement green and livable smart growth from the perspective of creating public policy (Matthias et al., 2014; Alan et al., 2017), spatial form integration (Elif, 2014; Liu et al., 2015), population structure optimization (Sykes and Robinson, 2014), growth boundaries limitations (Andrew, 2013), and renewal of old towns (Davide, 2016; Wu and Wang, 2017). How to realize urban green, livable and smart growth has become an attracting issue by constructing smart growth measure models (Khodeir et al., 2016; Kaveh and Kamruzzaman, 2017) to review its feedback (Boulos et al., 2015; Andrew and Sugie, 2017), and reshaping planning partition to stimulate urban vitality (Ali, 2014; Kiranmayi, 2015). On the contrary, Chinese scholars are using quantitative models (Tong et al., 2017; Wang and Qi, 2017; Yan et al., 2018) focusing on low density suburban spread patterns from the aspect of land consolidation and transformation (Li et al., 2014; Yang et al., 2017), ecological sensitivity (Cao et al., 2015; Kong et al., 2017), and Pareto optimal configuration (Long and Wang, 2016). With the rapid advancement of urbanization, the continual multidimensional decline of population, economy, and society has gradually become a new urban development issue (Cristina et al., 2016; Wu and Sun, 2017;

Zhou et al., 2017). Many researches have been devoted to defining urban shrinkage by demographic changes, including population ageing, losing population, declining fertility, lacking labor pool and soaring unemployment *etc.* (Hasse et al., 2014). In addition, migration caused by an overly intensive layout, social insecurity, climate disasters and resource depletion *etc.* also deepen this core connotation (Yang et al., 2015). It should be noted that some studies paid attention to different aspects in choosing the motive force of urban renewal development scientifically, including model construction, urban shrinkage classification, evaluation model construction, formation mechanism, and response mechanism (Jurgita and Jolita, 2015; Lin et al., 2017; Zhang and Li, 2017). Some scholars tried to find a general explanation of urban shrinkage paradox in China based on quantitative calculation method, elements comprehensive configuration to develop a compact urban space with higher quality at multiple geographical scales (Liu, 2016; Zhang et al., 2017).

Until now, domestic and international scholars have conducted both theoretical framework construction and meso-micro scale qualitative discussion on urban smart development. Existing studies have mostly regarded smart growth and urban shrinkage as two independent and separated branches without unified academic definition and macroscopic quantitative comprehensive analysis. Different from the simple superposition between the above two branches, smart development focuses on the comprehensive development quality of cities among multiple cross sections in the time series under the interregional driving effect. It will face up to the dialectical relationship between them in the urban life cycle, and try to realize the organic renewal of cities. Here, we attempt to construct a dynamic fitting model of urban land expansion, population growth, and economic development as well as the coefficient of variation for urban smart development, in order to characterize urban smart development situation quantitatively and specifically using 294 prefecture-level cities and above in China. It is different from the traditional research scale, aiming to measure the average development quality of cities in the time succession, and taking into account the balanced connections between them and ideal state. As a result, this paper discussed the evolution characteristics of urban smart development at regional, provincial and prefectural scales in China from different time dimen-

sions. Furthermore, we examined the disparity distribution of urban smart development at different scale and corresponding scale changes from 2000 to 2015, as well as determining its driving factors. Generally speaking, it is of positive significance to provide some references for achieving urban smart development, especially in revealing how to coordinate the rational allocation of land resources, guide the orderly flow of population, and regulate economic health growth *etc.*

## 2 Materials and Methods

### 2.1 Study area

Taking the administrative divisions of 2016 as a standard, we chose a total of 294 prefecture-level cities and above in China as our research objects. It included 4 municipalities, 15 sub provincial cities and autonomous regions of China. In addition to Macao, Hong Kong, and Taiwan Province of China, all states, leagues and regions in China were also removed because of incomplete data. It also excluded Sansha and Danzhou cities of Hainan Province, Shannan City of Tibet Autonomous Region, and Chaohu City of Anhui Province. Considering the relative consistent natural environment, continual spatial distribution, and matching social-economic development, this paper divided the whole research area into seven significant spatial regions from macroscopic

district scale as shown in Fig. 1.

### 2.2 Data sources

As the administrative division changes of municipal districts in prefecture-level cities are relatively frequent, we took the whole city's data as a unified statistical caliber. The above specific urban population data were mostly from the *China City Statistical Yearbook* (NBSC, 2000–2016). The statistical data of gross domestic product in various provinces (municipalities and autonomous regions) and some prefecture-level cities mainly came from the *China Regional Economy Statistical Yearbook* (NBSC, 2000–2014). It was calculated with smooth reduction according to average price index so as to eliminate the impact of price changes in different years. We also chose built-up area as the indicator of land urbanization using the *China City Construction Statistical Yearbook* (MOHURD, 1999–2015). Specifically, according to urban resident population, we regarded 90, 95, 100, 105, and 110 m<sup>2</sup>/person as ideal values of built-up area per capita in mega cities, megalopolis, large cities, medium cities, and small cities, respectively, and took a reference to 'Code for classification of urban land use and planning standards of development land (GB50137-2001)' (MOHURD, 2012). Some missing data were obtained by interpolation or trend analysis to ensure a scientific and objective result.



Fig. 1 Administrative divisions of China

## 2.3 Methods

### 2.3.1 Dynamic fitting model of urban smart development

On the basis of revising traditional urban land sizeable elasticity coefficient, we revised a dynamic fitting model of urban smart development (Zhou et al., 2016). By using a dynamic fitting coefficient called *CPE* as a calibration, we measured the correlation among urban population growth, land expansion, and economic development. The improvement of urban performance is the overall result of various factors including natural land endowment, economic material basis, and human labor subjects. Such large-scale population migration, land resource epitaxial extension, and economic regional difference are all natural processes of the urban life cycle, and they will stimulate urban form transformation to some extent. As a result, it creates a pattern of accelerated expansion, new normal smart configuration, and unrealized good-matching shrinkage among comprehensive structural factors in prefecture-level cities and above in China. Dynamic fitting model of urban smart development abandons the original concept of ‘blind growth’ and ‘eliminating contraction’, and mainly focuses on exploring the rational path of realizing land agglomeration and human settlements optimization under government policy support. In general, it is beneficial for planning reasonable stocks, optimizing space layout, improving interregional efficiency and creating urban vitality. The specific calculation formula is as follows:

$$CPE = \frac{1}{2} \left( \frac{CR_t}{PR_t} \times R \right) + \frac{1}{2} \left( \frac{CR_t}{ER_t} \times E \right) \quad (1)$$

where *CPE* denotes the degree of urban smart development; *CR<sub>t</sub>* is the average annual growth rate of urban built-up areas; *PR<sub>t</sub>* is the average annual growth rate of urban population; *ER<sub>t</sub>* is the average annual growth rate of gross domestic product; *R* is the urban land use restraint coefficient per capita which is calculated from construction area divided by the year-end population; and *E* is the constant coefficient of regional resident consumption which refers to Family Engel Coefficient of urban residents in the study area. All of the above-mentioned take the arithmetic average of relevant data during the time series of city *i*. This includes two related economic and population subsystems of the same significance accounts for both halves with land expansion

in the dynamic fitting model of urban smart development.

$$R = \frac{LP_t}{LPI_t} \bigg/ \frac{LP_0}{LPI_0} \quad (2)$$

where *LP<sub>0</sub>* and *LP<sub>t</sub>* represent per capita built-up areas of city *i* in the base year and target year separately; *LPI<sub>0</sub>* and *LPI<sub>t</sub>* denote the ideal per capita built-up areas of their scale categories in the above-mentioned years.

$$E = \frac{QP_t}{QPI_t} \bigg/ \frac{QP_0}{QPI_0} \quad (3)$$

where *QP<sub>0</sub>* and *QP<sub>t</sub>* indicate per capita gross regional product of city *i* in the base and target year. They are calculated by the real GDP divided by the population, and the real GDP is reconciled by the corresponding values from 2000 to 2015 and the price index; *QPI<sub>0</sub>* and *QPI<sub>t</sub>* show the consumer price index of their respective provinces in the above years.

### 2.3.2 Coefficient of variation of urban smart development

The coefficient of variation eliminates the influence of dimensions and the mean level of variables (Fitch et al., 2015; Raj et al., 2017). Accordingly, we improved and put forward the coefficient of variation of urban smart developments (*CVSD*), which was used to reflect the rules of dynamic evolution about urban smart development of statistical units during the research period. And it took into account the proximity effect among cities within the provincial scope. In order to further explore the urban heterogeneous contributions on the overall development quality in China among different sequential or geographical units, the coefficient of variation of urban smart development is specified as follow:

$$CVSD = \frac{Y_t - Y_0}{Y_t + Y_0} \times \frac{1}{x} \sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (4)$$

where *Y<sub>it</sub>* and *Y<sub>i0</sub>* represent dynamic fitting degree of urban land expansion, population growth, and economic development at the end and early study period separately of prefecture-level analysis unit *i*. Also, *Y<sub>t</sub>* and *Y<sub>0</sub>* stand for the dynamic fitting degree of the entire research area in the final and initial phase; *x<sub>i</sub>* is the specific value of fitting index,  $\bar{x}$  is its average value; and *n* is the number of analysis research units. The larger

larger the *CVSD* is, the greater differences of smart development degree appear. Otherwise the value remains relatively stable as the variation between each city is reduced.

### 3 Results and Analyses

#### 3.1 Spatial and temporal characteristics of urban smart development in China

We divided the research units into five categories, namely shrinkage lagged cities, shrinkage disordered cities, smart developing cities, growth disordered cities, and growth constrained cities, according to Jenks natural breaks method (Fouad K, 2012) on the basis of *CPE* value. This characterized and determined the mutual suitability of construction land layout and population structure changes as well as their benefit synchronization dynamic fitting trend relating to economic-social demands in prefecture-level cities and above during 2000–2015. In addition, we made reference for achieving smart development in prefecture-level analysis units.

##### 3.1.1 Sequential characteristics of urban smart development in China

A majority of shrinking cities (51.02%) from 2000 to 2008 consisted of shrinkage lagged cities and shrinkage disordered cities (Fig. 2). The transformation of land use structure was difficult to adapt to population mobility and economic growth, and generally it shows a tendency of excessive utilization shrinkage development. In contrast, only 14.97% of cities were in a disorderly sprawl state, especially as the construction land expanded rapidly. Thus, the Chinese government needs to adopt a scientific and rational planning zoning mechanism to guide the orderly migration of labor force and promote the healthy development of the economy.

The amount of smart development cities from 2008 to 2015 had risen by 42.86% compared to that for the period of 2000–2008, presenting a good trend of dynamic fitting development in China. However, the amount of growth disordered cities and growth constrained cities decreased distinctly, respectively, the decline rate even reached 64.76% and 84.09%. The proportion of over extensive shrinking cities steadily rose, which still accounted for more than half of the total data units. And the geographical units gradually transformed into smart developing and shrinking cities throughout time series. However, the amount of growth disordered cities and



**Fig. 2** The proportion of urban smart development classification in China from 2000 to 2015

growth constrained cities decreased distinctly, respectively, the decline rate even reached 64.76% and 84.09%.

##### 3.1.2 Spatial characteristics of urban smart development in China

From the aspect of regional scale, areas of central Northeast China, North China, Northwest China, and some western and southern cities were in the shrinkage disordered stage. The layout of construction land was difficult to adapt to the transformation of population structure and economic models from 2000 to 2008. The southwestern and eastern portions of Northeast China, North China and East China were considered to be smart development. The southeastern part of Southwest China and northern and east-central East China can be characterized as significant growth and should urgently realize land extensive use. From 2008 to 2015, the western part of Southwest China and central parts of Central China and East China all shrank in a disorderly method, except for Northwest China, southwestern North China, and most cities of Northeast China. The good fitting smart developing cities of economy-population-land basic elements appeared only in central North China, the edge of East China, eastern Northwest China, and northeastern Southwest China.

Based on the provincial scale, in addition to the northeastern Xinjiang Uygur Autonomous Region, the southeast part of the Tibet Autonomous Region, Qinghai Province and the entire Guizhou Province, there were also many places showing shrinkage disordered tendencies during 2000–2008. For instance, western Jilin, eastern Liaoning, northern Hunan, central Guangdong, northeastern Jiangxi, central and northern Sichuan, Anhui Province, eastern and southern cities of Yunnan Province, and most of the Zhuang Autonomous Region

of Guangxi, Heilongjiang, Gansu and Shaanxi provinces all had shrinkage disordered tendencies. The midlands of Fujian, Henan, and Yunnan provinces, southeastern part of Gansu, Guangdong, northern Hubei, south-central Hunan, and most of Jiangxi Province appeared to have been overwhelmingly smart developing cities. The growth disordered cities were located in the north-central Shandong Province, northwestern and southeastern parts of Zhejiang, Jiangsu provinces. Apart from the southern part of the Inner Mongolia Autonomous Region and Anhui Province, growth constrained cities were scattered across Jiangsu, Guangdong, and Zhejiang provinces (Fig. 3a). The spatial distribution patterns of urban smart development in China during 2008–2015 can be classified mainly as shrinkage disordered and smart developing cities. The geographical range of shrinkage disordered cities in Northeast China expanded, and it narrowed to distribution in north-central Gansu and northern Guizhou provinces. In addition, shrinkage disordered cities also appeared in central Zhejiang, Shaanxi, Hunan, eastern part of Sichuan, Fujian, northeastern Qinghai, southern and northern Hubei, southern Inner Mongolia Autonomous Region, and much of Hebei and Henan provinces. The industry centralizing ability and human capital quality needs to be greatly improved in these regions. Apart from the centralized distribution of smart developing cities in Shaanxi and Jiangxi provinces, a relatively decentralized distribution appeared in Liaoning, Guizhou, Henan, Sichuan, Hubei provinces, and the Inner Mongolia Autonomous Region. Besides the eastern Ningxia, western Gansu, the central part of Shanxi, Jiangsu, Yunnan, the Zhuang Autonomous Region of Guangxi and the marginal region of Hunan, Shandong, Anhui, and Zhejiang provinces had typical

representatives of this kind at the same time (Fig. 3b).

In terms of specific prefecture-level cities, Taizhou and Baishan cities had shrinkage lagged distribution, owing to the higher added value of industry and service industry as well as the rapid population growth. Taking Haikou and Sanya cities as ready-made examples, an obvious shrinkage disordered pattern emerged in Hainan Province. Harbin, Mudanjiang, Shizuishan cities and the three municipalities of Shanghai, Beijing and Tianjin were all in smart developing phases from 2000 to 2008. The amount of growth disordered cities and growth constrained cities accounted for 10.54% and 4.42% respectively of the total sample cities. Furthermore, Linzhi, Meishan, Lishui and Shaoxing cities were typical representatives of the latter (Fig. 4a).

In contrast, the shrinkage lagged characteristics in Chaoyang, Tongling and Lanzhou cities were clear during 2008–2015. The three municipalities of Beijing, Shanghai and Tianjin failed to break the Path-Dependence and Lock-in effect, and the coordinated development capacity in Jinan, Huangshan, Chengdu, Zhanjiang, Lijiang, Pu'er and Qujing cities remained to be enhanced to a higher level. The above cities all showed obvious shrinkage disordered characteristics. In addition, the smart development tendency of Tongliao, Chengde, Qinhuangdao, Tulufan, Chongqing, Quanzhou and Yiyang cities was truly advanced. It was also apparent that Yantai, Zhangye, Yangzhou, Chuzhou, Xiaogan, Xinyu, Changchun, Yan'an, Leshan and Zigong cities of Sichuan Province had a growth disordered phenomenon with unreasonable construction land layout. As typical growth constrained cities, demographic dividend and economic performance of Nantong and Guang'an cities depended too much on relatively low-efficient spread (Fig. 4b).

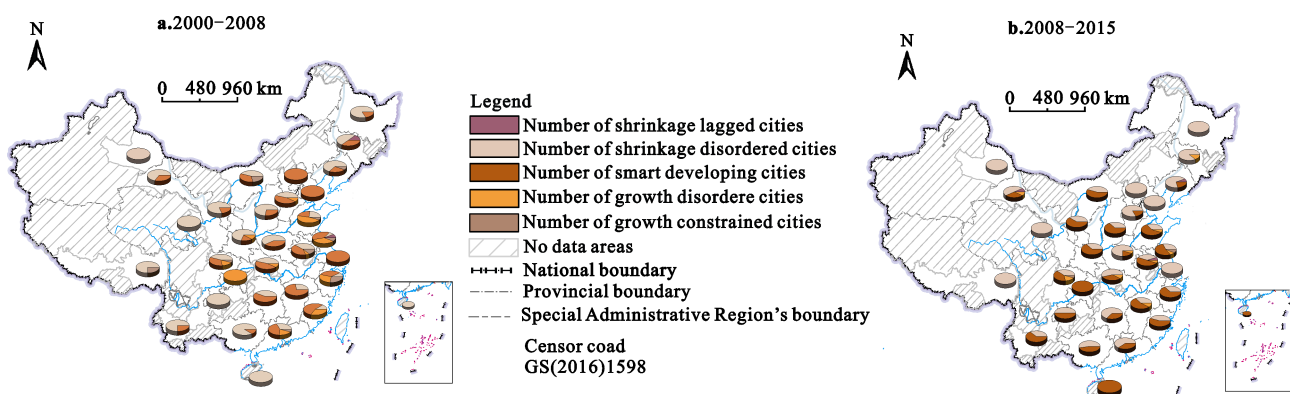


Fig. 3 Provincial characteristics of urban smart development in China from 2000 to 2015



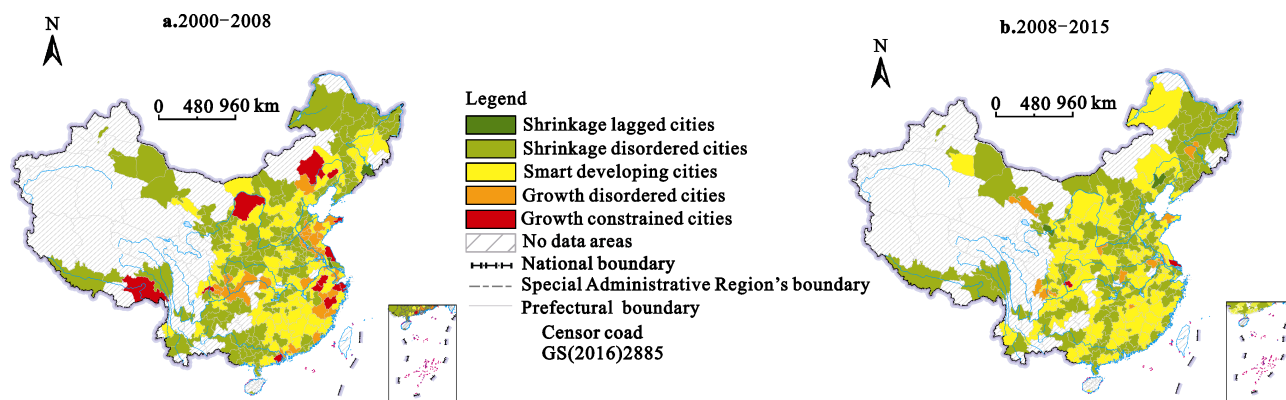


Fig. 4 Prefectural characteristics of urban smart development in China from 2000 to 2015

### 3.2 Heterogeneity of urban smart development in China

Throughout this time period (2000–2015), there is a further explanation describing the different evolution trends of urban smart development in China by using the coefficient of variation of urban smart development (*CVSD*). We took a specific classification of the geographical units into three kinds according to the value of *CVSD*, namely basic stable areas ( $\leq 0$ ), relative variable areas ( $0-1$ ), and significant variable areas ( $> 1$ ), so as to explore the multidimensional evolution law of urban smart development in China. All of Central Northeast China, except Tieling and Liaoyuan cities, southwestern and northeastern parts of East China, western and southeastern parts of South China, southeastern Northwest China as well as most of Southwestern China were all essentially in a stable development phase. From the provincial perspective, the dynamic fitting trend of built-up area expansion, population growth and economic development was relatively stable in east-central Jiangsu, western Henan, northern Hebei, southern Shaanxi, southeastern Gansu, southeastern Tibet Autonomous Region, eastern Guangdong Province, Xinjiang Uygur Autonomous Region, and south-central and northeastern Jiangxi Province. As for typical Baoding, Cangzhou, Zhangye, Sanya, Haikou, Chongqing cities *etc.*, they were still running with relative stability.

The provincial units with relative changing smart development were located in central Sichuan, Shaanxi provinces, northeastern Qinghai Province, northern Anhui Province except Suzhou City, northern Shandong Province except Dongying and Weifang cities, south-central Hubei Province except Xianning City, northern and eastern Zhejiang Province except Jiaxing and

Shaoxing cities, the central and northeastern part of the Inner Mongolia Autonomous Region except Baotou and Huhhot cities, and the entire Fujian Province except Ningde and Quanzhou cities. The degree of urban smart development varied greatly across the country and the layout of geographical space was relatively dispersed in Beijing, Tianjin, Shanghai, Zunyi, Tongren, Pu'er, Qujing, Shigatse, Chizhou, Xuancheng, Suzhou, Linfen, Jincheng, Hezhou, Guigang, Wuzhou, Karamay, Yinchuan and Zhongwei cities.

Comparing basic stable cities with relative variable cities, which accounted for 46.08% and 52.90% respectively of the dataset, only Lanzhou, Chaoyang and Tongling cities have undergone dramatic changes, transforming from shrinkage disordered and smart developing classification into shrinkage lagged classification (Fig. 5).

As for a differential evolution driving mechanism, Tongling City promoted copper-based new emerging industries strongly, which is regarded as an important node of the Yangtze River economic belt and a special transportation hub of south-central Anhui Province. However, the layout of construction land and population still could not fully adapt to the rapid economic development. As an important node of the Silk Road Economic Belt and one of the national new districts, Lanzhou City had an in-depth implementation of western development strategy and 'along-the-way' strategy. The migration of a large number of labor force promote economic-industrial structure and land-use patterns achieved a high-quality coordinated development. In addition, the mineral resource-based Chaoyang City was urgently exploring positive adaptations of population and employment transformation models while leading to an

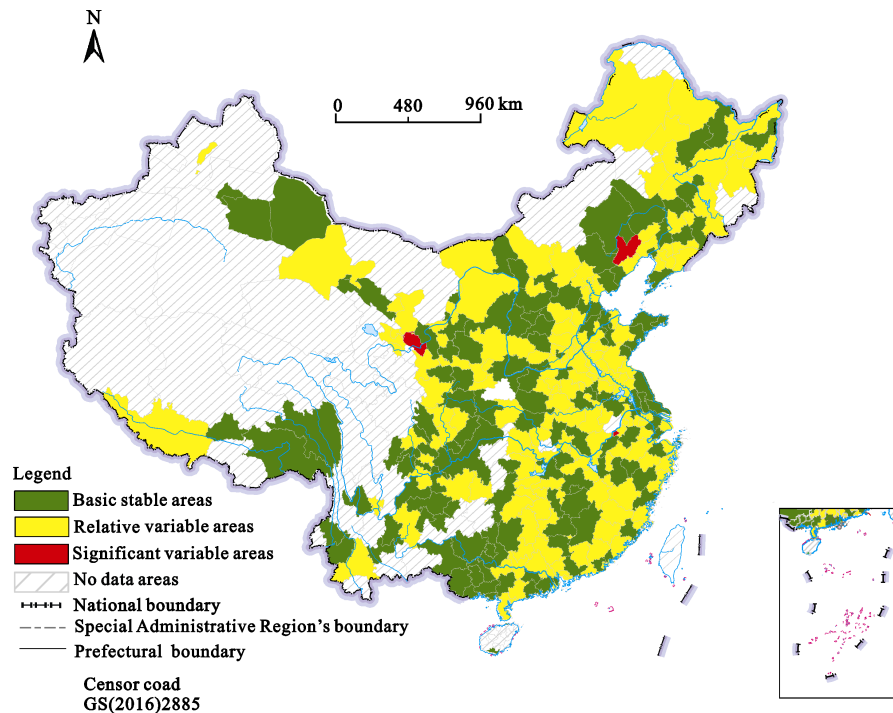


Fig. 5 The heterogeneity of urban smart development at prefecture level in China from 2000 to 2015

open spatial pattern due to the adjustment of administrative divisions. It was also a driving urbanization phenomenon with land finance as the core factor.

### 3.3 Characteristics of urban smart development with different scale and scale alteration in China

Taking the number of urban resident population in 2015 as urban scale division standard, we categorized the whole country into five kinds (Fang, 2014). While analyzing the statistical data units, it was not difficult to find that 70% of megalopolis and 80% of mega cities were in a shrinkage disordered stage advancing towards smart development (Table 1). Typical representatives of the above two kinds, such as Shenyang and Chongqing cities, had already achieved smart and coordinated development. Small cities, medium-sized cities, and large cities however were mainly characterized by shrinkage disorder and smart development. The population spatial agglomeration, industrial optimization, and land intensive utilization actively transformed from significant imbalance to basic synchronization.

From the perspective of geographical spatial layout, small cities in East China, including those in Anhui, Jiangxi and Gansu provinces, medium-sized cities in Central China including Xiaogan and Sanmenxia, and large cities Yantai and Changchun were characterized by

a growth disorder within this time frame. Sichuan Province especially accounted for 27.27% of the total amount of this kind of growth and covered several major urban scale classifications including small cities, medium-sized cities, and large cities. Therefore, the country should allocate land resource rationally according to local conditions and guide livable resident spatial construction orderly. Growth-constrained small city Guang'an and megalopolis cities Yangzhou and Nantong were facing great challenges resulting from administrative division reform, dramatic population decrease, *etc.* because of the coordinated allocation of population, economy, and land elements.

Large-scale population movement in a total of 108 prefecture-level cities occurred in China from 2000 to 2015, which was characterized by small cities developing into medium-sized cities (Table 2). These comprised up to 35.19% of the total. This occurrence was mainly distributed in the Zhuang Autonomous Region of Guangxi, eastern Hebei, central Henan, and most of Jilin. Shrinkage disordered eastern cities such as Chaoyang, Puyang, Suqian, Jinhua, Jingdezhen and other smart developing southeastern cities such as Yichun, Fuzhou, Chengde, Shangrao, Zhaoqing, Huaihua, Yiyang, Chenzhou, Maoming *etc.* brought this kind of scale variation to the surface.



**Table 1** Characteristics of urban smart development with different scale in China

City classification	Urban resident population ( $10^4$ people)				
	Small cities	Medium-sized cities	Large cities	Megalopolis	Mega cities
	(<50)	(50–100)	(100–500)	(500–1000)	(>1000)
Shrinkage lagged cities	1	1	1	0	0
Shrinkage disordered cities	51	61	34	7	4
Smart developed cities	45	42	32	1	1
Growth disordered cities	4	3	3	1	0
Growth constrained cities	1	0	0	1	0
Total amount	102	107	70	10	5

**Table 2** Characteristics of urban smart development in China with scale changes from 2000 to 2015

City classification	The amount of cities with scale changes				
	Small to medium	Small to large	Medium to large	Large to megalopolis	Large to mega
Shrinkage lagged cities	1	0	0	0	0
Shrinkage disordered cities	20	0	9	6	1
Smart developed cities	15	2	8	0	0
Growth disordered cities	2	0	0	0	0
Growth constrained cities	0	0	1	0	0
Total amount	38	2	18	6	1

City classification	The amount of cities with scale changes				
	megalopolis to mega	megalopolis to large	Large to medium	Large to small	Medium to small
Shrinkage lagged cities	0	0	0	0	0
Shrinkage disordered cities	1	0	9	7	7
Smart developed cities	1	0	6	1	8
Growth disordered cities	0	0	1	1	1
Growth constrained cities	0	0	0	0	0
Total amount	2	0	16	9	16

Over the study time period (2000–2015), there were 41 cities scaling down which account for 37.96% of total units with scale variation. Suining, Neijiang, Yichang and neighboring Changde cities, western Henan Province, and provincial boundary of southern Shandong Province as well as Zhanjiang City (the southernmost port city of Guangdong Province) are typical disordered geographical units. These all adopted various measures to transfer a surplus labor force while meeting the needs of the local market economy and industrial restructuring. In addition, Guigang, Qinzhou, Wuwei, Linzhi, Jingzhou, Bazhong and other mid-western cities had an obvious relative imbalance between population contraction and economic progress while decreasing from large cities into small cities. Apart from coal-dominated cities Shuangyashan and Qitaihe, Suizhou, Pingxiang, Zhumadian, Guangyuan and other mid-southern cities also had a clear shrinkage-disordered tendency in the transition from medium-sized cities to

small cities. Smart development was still achieved during scale shrinkage fluctuation of large cities, for example, Tai'an, Laiwu, Liaocheng and Rizhao cities of central Shandong Province as well as Tianshui, Zhenjiang and Ziyang cities. Smart developing paradigms transforming from medium-sized cities to small cities were mainly distributed in adjacent provinces including Shaanxi, Henan, Anhui and Hubei provinces along with Yangjiang City of Guangdong Province. Moreover it accounted for nearly half of the total reduced scale changing areas.

### 3.4 Driving forces of urban smart development in China

Shrinkage disordered cities shifted from spatial relative distribution to centralized distribution in Northeast, North and Central China during the study period, and the number of growth disordered and growth constrained cities dropped sharply. In addition, the number

of smart developing cities distributed in South, Southwest, Northwest and East China increased more than 20% compared to the initial stage. On the whole, these cities have achieved not only an intensive use of land and a steady flow of population, but also a stable and healthy development of the economy. Based on the above mentioned analysis and existing related research findings, the driving mechanism and influencing factors of spatial and temporal heterogeneity of urban smart development in China can be categorized to five major types (Table 3). Specifically, it contains natural geographical factors, industrial structure adjustment, human capital radiation, regional traffic accessibility, and government decision-making intervention. There are positive and negative effects of different factors on the spatial and temporal heterogeneity of urban smart development.

Generally speaking, according to the member variables and their significance, the influence of environment factors was weaker than that of socio-economic factors. Except human capital radiation driving factor, other four aspects were all extremely significant and important, but the influencing degree was different.

However, instead of material effects on spatial and temporal differential evolution of urban smart development in China, the elements related to human capital are the essential foundations and main subjects of urban lifecycle. Human spatial self-organization will gradually drive the city to achieve smart development. From the overall effects, these five aspects are further explained below to identify the reasons for spatial and temporal heterogeneity of urban smart development.

#### (1) Natural geographical driving factors

Northwest China is a series of plateaus and basins with serious land desertification and shrinkage disordered phenomena compared with other geographical units. The innate endowments vary greatly and the land use efficiency of built-up areas needs to be improved. Cities of East China are mostly located along southeastern coasts with a humid, livable climate, relative reasonable mechanism of population mobility, and economic transition. The natural geographical factors including ecological environment, play an important role in the industrial structure layout and population agglomeration level, so to a certain extent they promote the achievement of urban smart development. Land area

**Table 3** Preliminary analysis of influencing factors of urban smart development in China from 2000 to 2015

Variable category	Description	Quantity unit	Impact	Sig. in 2000	Sig. in 2015
Dependent variable	Spatial and temporal differential evolution of urban smart development		—	—	—
Natural geographical factors	Land area	km <sup>2</sup>	+	0	0
	Build-up area	km <sup>2</sup>	+	0.594	0.664
	Paved road total area	ha	+	0	0.907
	Urban ornamental green area	ha	+	0.223	0.971
Industrial structural adjustment	Industrial sulphur dioxide emissions	t	—	0.197	0.255
	Discharge rate of industrial waste water	%	+	0.060	0.740
	Constant GDP	10 <sup>4</sup> yuan (RMB)	+	0.529	0.094
	Aggregation degree of secondary and tertiary industry	10 <sup>4</sup> yuan (RMB)/km <sup>2</sup>	+	0	0
Human capital radiation	Year-end total population	10 <sup>4</sup> people	+	0.273	0.247
	Employed workers	10 <sup>4</sup> people	+	0.010	0.314
	Full-time students in colleges and universities	people	+	0.982	0.929
Regional traffic accessibility	The amount of public bus and trams		+	0.376	0.182
	Total passenger volume	10 <sup>4</sup> people	+	0.032	0.929
	Total cargo volumes	10 <sup>4</sup> t	+	0.433	0.008
	Business total of posts and telecommunications	10 <sup>4</sup> yuan (RMB)	+	0.406	0.014
Government decision-making intervention	Investment in the fixed assets	10 <sup>4</sup> yuan (RMB)	+	0.039	0.774
	Foreign actual investment	10 <sup>4</sup> dollars	+	0.438	0.009
	Location in country's system		+	0.629	0.923

Notes: '+' denotes positive effect and '—' shows negative effect on spatial and temporal differential evolution of urban smart development separately. The factors with sig. value less than 0.05 are significantly correlated with the dependent variable.

and environmental cleanliness have positive impact on urban smart development, which is consistent with our expectation.

### (2) Industrial structural adjustment driving factor

To some extent, knowledge, innovation, and technological advancements will lead to superior property rights in promoting the rational optimization and upgrading of the industrial structure, so as to achieve a coordinated and healthy development of cities. Coastal cities of East China and South China are relatively advanced in investment destiny and openness with more matching of funds and techniques. It is easier to attract foreign labor when better infrastructure is in place, and then lead to the formation of smart growth within cities, growth disordered cities, and growth constrained cities. However, in Northeast and Northwest China, there is an inherent under-powered resource dependent industry causing the lack of industrial structure reformation. Urban revitalization falls into the land-finance addicted dilemma to a large extent and results in growth disordered cities with inferior coordinated development of population-economy-land basic elements.

### (3) Human capital radiation driving factor

The average schooling year of the Tibet Autonomous Region and Xinjiang Uygur Autonomous Region, *etc.* is at a comparable disadvantage, particularly compared to the above national-average human capital quality of Beijing, Tianjin, and Shanghai municipalities. Excessive dependence on productive inputs while neglecting human capital and investment structure results in a clear

imbalance of economic and regional human capital accumulation to a certain extent. On the national scale, the overall advanced economic environment in East China leads to a significant number of smart developing cities in Midwestern areas.

### (4) Regional traffic accessibility driving factor

Regional traffic accessibility promotes economic trade activities and forms population agglomeration with the help of transportation trunks and hubs. These transportation centers help to create the core of metropolitan areas and optimize the allocation of resources. They also help shape diversified development modes. Making manual reference on urban smart coordinated development experience, it is beneficial to curb the disorderly sprawl of urban land for convenient transportation infrastructure construction and complementary traffic locations. Some provincial capital cities and their adjacent areas turn into economic growth poles because of the regional traffic advantage, thus the heterogeneous classification of urban smart development is generated.

### (5) Government decision-making intervention driving factor

Administrative division reform dominated by government results in significant change of built-up areas and strengthened mobility of the population. While delineating the ecological urban growth boundary and encouraging redevelopment of stock land, the government also plays an important role in public service facilities' configuration, employment guidance and investment structure optimization (Fig. 6).

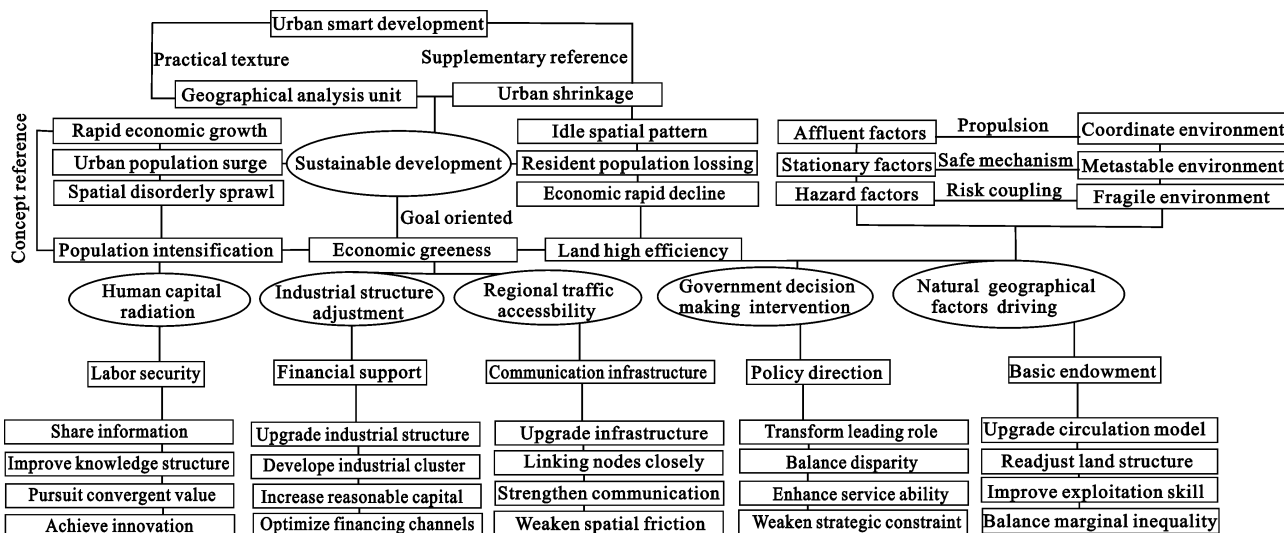


Fig. 6 Driving mechanism of urban smart development in China from 2000 to 2015

## 4 Discussion

### 4.1 Urban smart development in China from 2000 to 2015

Although the existing researches concerned about scale changes, population movements and economic construction in specific cities or parts of the country (Huang et al., 2018; Liu et al., 2018), they all measured urban or regional development degree with index system from single horizontal or longitudinal perspective (Wang et al., 2015). The purpose of this study was to address questions about how to realize comprehensive development by combining smart shrinkage and smart growth scientifically, and taking the impact of time period into consideration. Finally, we obtained a clearer analysis of heterogeneity of urban smart development in China, the result of which is similar to other researches, but also different in other ways. We deeply revised a dynamic fitting model *CPE* to measure overall quality of prefecture-level cities and above in China. It shows double highlights of shrinkage disordered cities and smart developing cities in China within the time scale from 2000 to 2015, while the degree of urban smart development was actively advancing. Compared with the metropolitan region, the degree of urban smart development in regional, provincial and prefectural aspects exhibits relative obvious advantages (Liu et al., 2013). By using this kind of mathematical econometric method, the appearance of shrinkage disordered cities could not be neglected. And the spatial distribution of areas with basic stability and relative variation were dispersed approximately proportionally, the latter even exceeded half of the research units. This may be due to the consideration of gap between the actual development situation and the ideal level during study period. It is more consistent with the stunning urbanization fact to some extent (Gu et al., 2017). Besides, there was much to be learnt from the smart development paradigm in East China (Liu et al., 2018). The three municipalities of Beijing, Tianjin, and Shanghai transformed into shrinkage disordered development cities from urban smart coordination, and Chongqing Municipality finally achieved a good balance among the various factors. In addition, *CVSD* was fully utilized to study the spatial and temporal differential characteristics of urban quality as time went by. It avoided the effect of geographical proximity or temporal evolution rule imposed on urban

smart development. As a result, the trend of urban smart development in prefecture-level cities and above in China kept stable from 2000 to 2015. The variance of population emerged in more than 1/3 of the cities in the continuous time domain, and it mainly reflected several kinds of areas including small cities transitioning into medium-sized cities, medium-sized cities transitioning into large cities, large cities transitioning into medium-sized cities, and medium-sized cities transitioning into small cities. Polarization of shrinkage disordered and smart developing cities was very obvious, accounting for 55.56% and 37.96% of total number of prefecture-level cities and above in China with scale variation respectively. Actually, prefecture-level cities and above in China also grow in a sequential order. Cities with the best economic conditions may be the first to grow until they reach a critical size and then their growth rates slow down (Sheng et al., 2014). Discontinuity of urban scale changes will also effectively improve the degree of urban smart development in this study.

### 4.2 Determining factors and influencing mechanism of urban smart development

At the same time, we tried to use preliminary mathematical analysis of influencing factors of urban smart development as a means for explaining the driving forces and comprehensive mechanism in the impact of various factors. In view of positive or negative feedback and the extent of iteration between dependent variable and associated factors, then the impact mechanism can be determined more accurately. It will make up for the lack of existing researches to a certain extent, and provide a reference for theoretical and practical research in related fields. From the perspective of influential mechanism, the heterogeneity of urban smart development in China resulted from several contributing factors including natural geographical factors, industrial structure adjustment, human capital radiation, regional traffic accessibility, and government decision-making intervention. Moreover, the driving mechanisms exist separately in different phases. Industry restructuring adjustment and regional traffic accessibility present an obvious economic development trend. Meanwhile, human capital radiation factors emphasis on achieving population agglomeration growth through cultivation and introduction model of high quality talents. As for government decision-making intervention and natural geographical

factors, these induce rational distribution of urban construction land from a land efficient utilization standpoint. However, aforementioned analysis shows that it is of great importance to enhance the comprehensive and profound degree of research on urban smart development, we attempt to introduce an econometric approach into relating sciences of urban development.

### 4.3 Improvement for the researches on urban smart development

The ecological civilization concept under a background of new normal economic notion will weaken economic progress and construction land expansion. We argued that some effective measures should be taken to alleviate the urban pressure. Moreover, we should try to integrate ecological environment factors into the calibration of urban smart development categories and estimate the quality of urban comprehensive development on the premise of ensuring ecological friendliness. Then we may make a more reasonable division and definition of urban smart development. Secondly, our empirical findings demonstrated that the role of floating population on land expansion and economic development should not be underestimated. Thus, we ought to take a further consideration of the driving mechanisms on temporal and spatial differential patterns of urban smart development imposed by a floating population in the long-run. Thirdly, the applicability of the preliminary establishment of *CPE* and *CVSD* model needs to be improved and promoted into empirical application. In addition, due to the difficulties pertaining to the acquisition of related statistical data, the spatial and temporal differential pattern of urban smart development and its driving mechanism using county-level cities as data samples requires further discussion. Future research will focus on coping and regulating these strategies, in order to explore differentiated methods for various cities.

## 5 Conclusions

Smart development is regarded as a logical reconstruction of economic development based on the rational stock of land and the orderly migration of population. It aims to promote the efficient transformation of urban development model, and improve the overall comprehensive prefecture-level cities and above. We perfected a dynamic fitting model of urban smart development by

taking dynamic fitting coefficients of urban land expansion, population growth, and economic development called *CPE* as a calibration to measure the coordinated relationship among each basic element, and took into account the development gap compared to the ideal level in a quantitative way. This model can be used to determine the degree of smart development in the micro-level such as provincial and prefectural geographical units. According to the degree of urban smart development, we classified 294 prefecture-level cities and above in China into five categories, namely shrinkage lagged cities, shrinkage disordered cities, smart developing cities, growth disordered cities and growth constrained cities. The purpose of this study was to address questions about how to measure urban smart development degree and how to reflect urban smart development changing tendencies scientifically in prefectural, provincial, and regional geographical units. In addition, we judged the fitting difference of overall urban smart development degree in the course of temporal evolution with regional unit interactions by *CVSD*. It eliminated the interrelationship among provincial geographical units between time and space double aspects.

Up to now, the provincial and regional differentiation and imbalanced distribution of urban smart development in China are already less obvious compared to the previous stage of 2000–2008. Each space element has been optimized and well reorganized, and they are making great contributions to push forward urban smart development. While in terms of prefecture-level cities, it revealed that spatial and temporal heterogeneity of urban smart development still existed, to some extent, with the spatial heterogeneity more obvious than the temporal heterogeneity. The disordered growth tendency of prefecture-level cities and above in China is overall well controlled in the middle, and late research stage of 2008–2015. It mainly presented a doublet coexistence of shrinkage disordered cities and smart developing cities. It is particularly more obvious that Northeast China and East China have been regarded as shrinkage disordered cities and smart developing cities as main development tendency separately. Areas with basic stability and relative variation were relatively dispersed in the time series, and it mostly demonstrated a relative equilibrium spatial and temporal differential characteristics of cities in China, except for Tongling City of Anhui Province, Lanzhou City of Gansu Province and Chaoyang City of



Liaoning Province.

Apart from accomplishing dynamic comparisons among China's cities in different time series, we also attempted to explore methods and countermeasures for realizing urban smart development. There are five interactive objects including natural geographical factors, industrial structure adjustment factors, human capital radiation factors, regional traffic accessibility factors, and government decision-making intervention factors, all these factors play an important role in forming driving mechanism in the process of urban smart development.

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