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Spatial pattern, and evolution of China's urban agglomerations

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Abstract

China's urban agglomeration is not only crucial to tackle with the more and more contradiction between population, resources and environment, but also an important spatial actor to increase the global competitiveness and promote the transformation of China's economic development mode. In the national "14th Five-Year Plan" in 2021, it is proposed to "promote the coordinated and development of large, medium-sized and small cities and towns based on urban agglomeration and metropolitan area". Generally, 19 urban agglomerations designated in this Plan are heterogeneous in development level and national functions. To this end, from the nature of urban agglomerations, especially on agglomeration economy and functional urban region hypothesis, the research focuses on the spatial pattern and changes of these 19 areas mainly based on the 6th and 7th national census. The findings show that, China's UAs are unique in driving forces, and spatial patterns as well. China's UAs are more state-led, though now the marketing forces more and more crucial. The UAs have been evolved from the early planned economy period to the reform and opening up period, and then to the further development of the Socialist market economy until now. Unlike other typical UAs abroad, most of the developed UAs are more specialized in manufacture, not in producer services, though these regions show a remarkable high-end services oriented shift in 2010–2020.

Keywords Urban agglomerations (UAs), Spatial pattern and evolution, Functional urban region, Paradigm shifts

Although China's research began to study regional issues related to urban agglomeration (UAs) as early as the start of reform and opening up, such as metropolitan interlocking region, urban belt, and even putting forward the concept of "urban agglomeration" in 1990s. However, from the national level, it was not until 2006 that the "urban agglomeration" spatial strategies was first proposed in the national "11th Five-Year Plan", i.e., "urban agglomeration as the main form of urbanization". After that, UAs have received extensive attention and played more and more important roles.

Global research on UAs can be traced back to Gottmann's Megalopolis study in 1957 (Gottmann, 1957),

which focused on the Northeast Coast of the United States. After Megalopolis, the concepts related to UAs, such as Global-city Region (Sassen, 2001; Scott, 2001), Metropolitan Regions, Mega City-region (Hall et al., 2006; Yu and Wu, 2006), Megaregion (Innes, 2011; Yu, 2022), Global Region (Wu, 1998; Wu, 2002) emerged worldwide. Though different in regional scales and socio-economic background, these concepts all emphasize the principals of scale economy or agglomeration economy, emphasize the dominance of central cities, especially the mega cities (Wu, 2000; Gu et al., 2002). Since 2000, there are two concepts that attracting the most attention. The first is the "Mega Region" in USA and the other is the Polycentric Mega City Regions in EU. In terms of geographical scope, spatial organization, China's UAs are more similar to Mega Regions, while the Metropolitan Regions (*Dushiquan*) in China's 14th five -year Plan (2020–2025) more to Mega City Regions (Yu, 2022).

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China's 14th five-year Plan proposes "to promote the development of UAs to comprehensively form a strategic urbanization structure of 'two horizontal and three vertical' pattern". In fact, the 19 UAs designated in the Plan vary sharply in sizes, functional specialization, development stages, resilience to risk, and input–output performances. Therefore, this paper tries to analyze the actual spatial pattern and changes especially since 2008, with comparison to the Plan. The paper includes the followings parts: firstly, to construct an analysis framework from perspective of agglomeration and functional urban areas; Secondly, by using employment data from 20 employment sectors in the 7th National Population Census of 2020, to quantitatively analyze the development status or pattern of UAs in China; thirdly, to analyze the evolution process of UAs in China and identify their uniqueness. The last part is the discussion of China's UAs paradigm shifts.

1 Outline of 19 UAs designated in the 14th five-year plan in China

The 19 key UAs in the "14th five-year Plan" are Yangtze River Delta region, Huhhot-Baotou-Ordos-Yulin region, Pearl River Delta region, Beijing-Tianjin-Hebei region, Guangdong Fujian Zhejiang Coastal region, North slope region of Tianshan Mountains, Middle reaches of Yangtze River, Shandong Peninsula region, Central Yunnan region, Central and Southern Liaoning, Chengdu-Chongqing region, Ningxia region along the Yellow River, Zhongyuan region, Central Shanxi region, Guanzhong Plain region, Central Guizhou region, Harbin-Changchun region, Beibu Gulf region, Lanzhou-Xining region. Among the 19 UAs, five are in the East region, three in the Middle region, nine in the West region and two in the Northeast region².

According to the 2020 data, these 19 UAs totally occupy about 1/4 of the country's land area, have more than 80% of the country's GDP and more than 70% of the total population. And some of these UAs act as innovation-driven competitors in the world, such as the Yangtze River Delta, the Pearl River Delta and

Beijing-Tianjin-Hebei, some are important for national urbanization strategy and regional coordination, such as the Zhongyuan Region and the Middle reaches of Yangtze River, and some play as important raw material and energy supplying roles, such as the Huhhot-Baotou-Ordos-Yulin region Table 1. These 19 UAs have different socio-economic performance in terms of GDP efficiency, resilience and risks in the context of economic crisis, Fig. 1 and Table 2.

2 Spatial patterns of China's UAs based on agglomeration and function perspective

2.1 Agglomeration economy and functional urban region: key concepts for understanding UAs

From views of New Economic Geography (NEG), UAs have advantages on production factors, infrastructure capacities, and socio-economic resilience as well, because of the economy of scale and agglomeration (Krugman, 1998; Fujita et al., 1999). From this, they will attract certain enterprises and human capitals to promote outputs, and can further stimulate the increasing investment expenditures among actors (Glaeser, 2012). Economists believe that the essential agglomeration economy nature of UAs benefits the enterprises from the proximity to the "labor pool", diversified suppliers, professional services and good external connections (Rice et al., 2006), by costs reduction, economic productivity and elasticity improvement.

Methodologies of defining and mapping the city-region share two common features—an urban-centric view of the region and an economically driven approach. These are further elaborated by focusing on the prevailing conception of the city-region as a functional economic space and the dominant top-down approach to delineate the boundaries of what is known as the functional urban region (FUR) (Sinin, 2020; Yu, 2022). So the city-region is depicted as an integrated economic entity. The FUR approach to city-region definition has been further advanced by regional studies from Mike Coombes and Paul Cheshire in Britain as well as through pan-European research programs (ESPON).

Table 1 Location and regional roles in different scales of China's UAs

Location typologies	Urban agglomeration	National functions
Border areas	Beibu Gulf region Harbin-Changchun, Central Yunnan region, Huhhot-Baotou-Ordos-Yulin region, North slope region of Tianshan Mountains	Serve the Belt and Road Initiative
Hinterland areas of West China	Chengdu-Chongqing region, Guanzhong Plain region, Central Guizhou region, Lanzhou-Xining region, Ningxia region along the Yellow River	Regional coordination
Hinterland areas of Middle China	Middle reaches of Yangtze River, Central Shanxi region, Zhongyuan region	Regional gradient transfer type
Global Regions	Beijing-Tianjin-Hebei region, Yangtze River Delta region, Pearl River Delta region	global competition and innovation
Coastal gateway	Shandong Peninsula region, Guangdong Fujian Zhejiang Coastal region, Central and Southern Liaoning	Link the world and the inland



Fig. 1 19 UAs and Their Spatial Boundaries in the National 14th Five -Year Plan

2.2 Outlines of the agglomeration and functions of city regions in China

The employment density and structure are the basic characteristics of an urban area. Employment density largely reflects the agglomeration of cities. According to the 2020 census, county level cities with employment density exceeding 750 person/ km² are mostly distributed in the East coast regions, with the vast majority concentrated within the central areas of prefecture level cities. The units with employment density of 300 person/km² are relatively concentrated in areas where usually traditional cities existed and flourished like the Hunan-Hubei region, North China Plain, Henan

Province, Fen and Wei River Plain, Sichuan Basin. On the basis of the population census on the employment in different industries, the employment of non-agricultural sectors was further classified and merged to "mining-manufacturing-consumer service- high end service- Public service" structure. Adjacent counties and urban areas with urbanization levels higher than 65% were merged to one units. From Figs. 2 and 3, the degree of specialization and agglomeration in manufacturing and high-end service industries is mostly concentrated in the East Coast China and some provincial capital cities. The Middle China shows a more diversified industrial pattern. The Northeast China is

Table 2 Basic data of 19 UAs in 2020

	Land cover (km ²)	GDP in 2020 (Billion Yuan)	Total Population / thousand	GDP per capita	Fiscal revenue per unit of GDP	Fiscal overdraft level
Beijing-Tianjin-Hebei region	147,466	6780.3	67,920	99,823	13.1	59
Yangtze River Delta region	226,091	21,197.7	174,210	121,682	11	27.9
Pearl River Delta region	128,665	9724.1	94,850	102,517	9.2	50.1
Chengdu-Chongqing region	224,497	6747.4	101,250	66,643	7.6	129.8
Middle reaches of Yangtze River	301,827	8639.5	112,970	76,476	6.6	153.4
Shandong Peninsula region	158,429	7309.3	101,470	72,031	8.7	60.1
Guangdong Fujian Zhejiang Coastal region	69,732	4597.4	48,720	94,371	6.9	63
Zhongyuan region	99,648	4252.7	71,430	59,539	7.7	104.3
Guanzhong Plain region	134,580	2178.1	41,010	53,111	6.1	235
Beibu Gulf region	115,690	2057.7	43,870	46,905	6.2	201.5
Harbin-Changchun	279,447	2046.8	43,520	47,034	6.6	275.8
Central and Southern Liaoning	82,850	2110.9	30,430	69,366	10.4	71.7
Central Shanxi region	58,574	887.2	15,480	57,327	10.2	111.5
Central Guizhou region	74,921	1101.9	21,940	50,231	7.8	189.6
Central Yunnan region	64,890	1175.1	16,390	71,718	8	81.8
Huhhot-Baotou-Ordos-Yulin region	174,757	1321.2	11,910	110,955	9.3	77.1
Lanzhou-Xining region	70,847	571.2	12,330	46,341	8.2	210.2
Ningxia region along the Yellow River	48,655	356.8	5520	64,665	6.6	268.6
North slope region of Tianshan Mountains	21,523	422.4	4540	92,950	11.2	37.4

relatively specialized in consumer and public service, while the West is more in public service.

2.3 Delimitation of spatial pattern based on agglomeration and FUR

Based on perspectives of agglomeration and FUR, the methods of defining China’s UAs are as follows: ① Analyze the employment scale and share of high-end service industries in cities, to preliminarily determine the core cities with strong agglomeration; ② Identify typology of functional areas. At the national level, based on the employment population density at the county level units, evaluate which units are "core" areas, and which are "peripheral" for UAs.

Generally speaking, the less developed areas have lower density of employment; in urban areas, the density of employment is relatively high, and the most developed have the highest density. According to this, we can divide the core, peripheral and even marginal areas of the region, and judge the economic type of each region according to the structure of sectors. According to the Concentric zone model, the central city is mainly specialized on tertiary sector, especially on finance, commerce, culture and information processing; The less developed surrounding units as peripheral regions, usually have high proportion and density of technology, colleges and universities, or transportation and logistics; The third

zone is mainly specialized more on recreation and industrial areas; The fourth is usually agriculture dominant marginal regions (Yu and Wu, 2006).

This study begins by dividing the country into 2844 county level geographic units. These units are hypothesized to be homogeneous and uniform. Furthermore, we opt for a subdivision into 40 indexes based on the spatial density and structures of employment of sectors in each separate geographic unit, and go on the subjecting the 40×2844 matrix to Principal Component Analysis in order to explore the main relationship in territorial labor divisions and agglomeration across the country (Champion and Monnesland, 1996). Then the typologies of units are clustered and derived, including the spatial structure types and the economic structure types.

Ten components are extracted which account for 84% of the variance in regional economic development, and their degree of association with the 40 individual indexes is shown in Table 3. These 10 principal components reflect the agglomeration and functional characteristics of cities. Components 1, 8, and 9 more reflect the agglomeration characteristics of high-end service and other sectors; Components 2,3,4,5, and 10 reflect the functional characteristics such as high-end service, public sector service, consumer service, while 6 and 7 reflect the agglomeration and specialization simultaneously of manufacturing industry and international organizations.

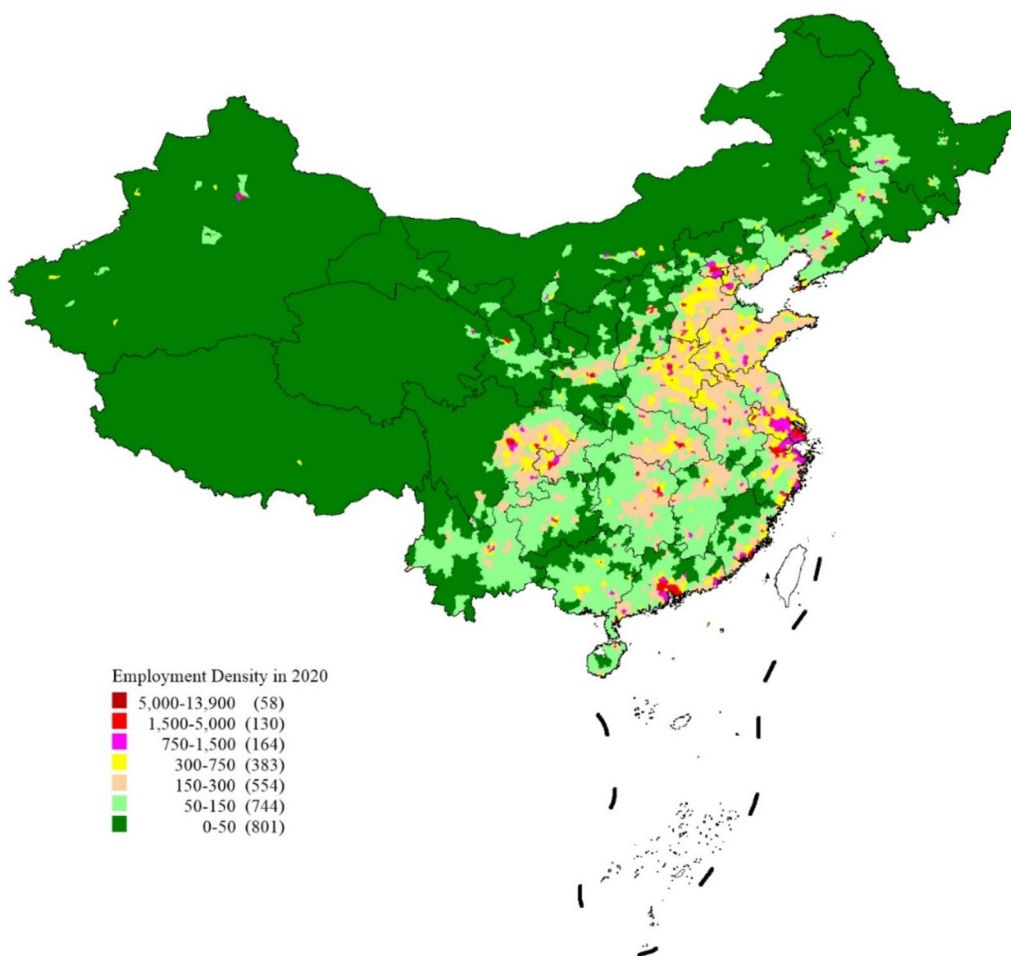


Fig. 2 Agglomeration of China Based on Employment Density

The development level and functional specialization of 2844 units in China is shown in Figs. 4 and 5. Overall, the units with the highest level of development are the central areas of prefecture level cities, especially those of provincial capital cities. Another obvious feature is that the well developed county-level units are usually located around the mega cities on the one hand, highly distributed in the East China on the other hand, and the third is the morphological characteristics of UAs reflecting the current urban development in China.

2.4 Uniqueness of China’s UAs functional pattern

In terms of specialization, after nearly 40 years of reform and opening up and economic development, the functional pattern of urban areas has shown significant spatial pattern, Fig. 6. On the one hand, most of the counties and urban areas in the East are highly specialized in manufacturing. The West is more specialized in public services. The Northeast is mining industries. The densely populated Middle China is consumer services. In the Liaohe

River basin, Shandong and Henan, and the Beibu Gulf region, the specialization is mainly in agriculture, forestry, animal husbandry, and fishery. On the other hand, cities with bigger sizes, especially prefecture level city districts, tend to specialize in high-end service, especially those provincial capital cities.

China’s UAs labor division or specialization has a remarkable uniqueness. Generally, competitive UAs usually have big size and high proportion in the high-end service, and play a global control and command influence. The performance of the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei is particularly outstanding. In 2020, the total employment of their high-end service exceeded 5 million, especially in the Yangtze River Delta region, with a scale of up to 8.83 million; The Chengdu-Chongqing region and the Middle Reaches of the Yangtze River region have high-end service employment scales of 3.58 million and 2.97 million, respectively. The vast majority of UAs in the West China are less developed in high-end service sectors, for example, the

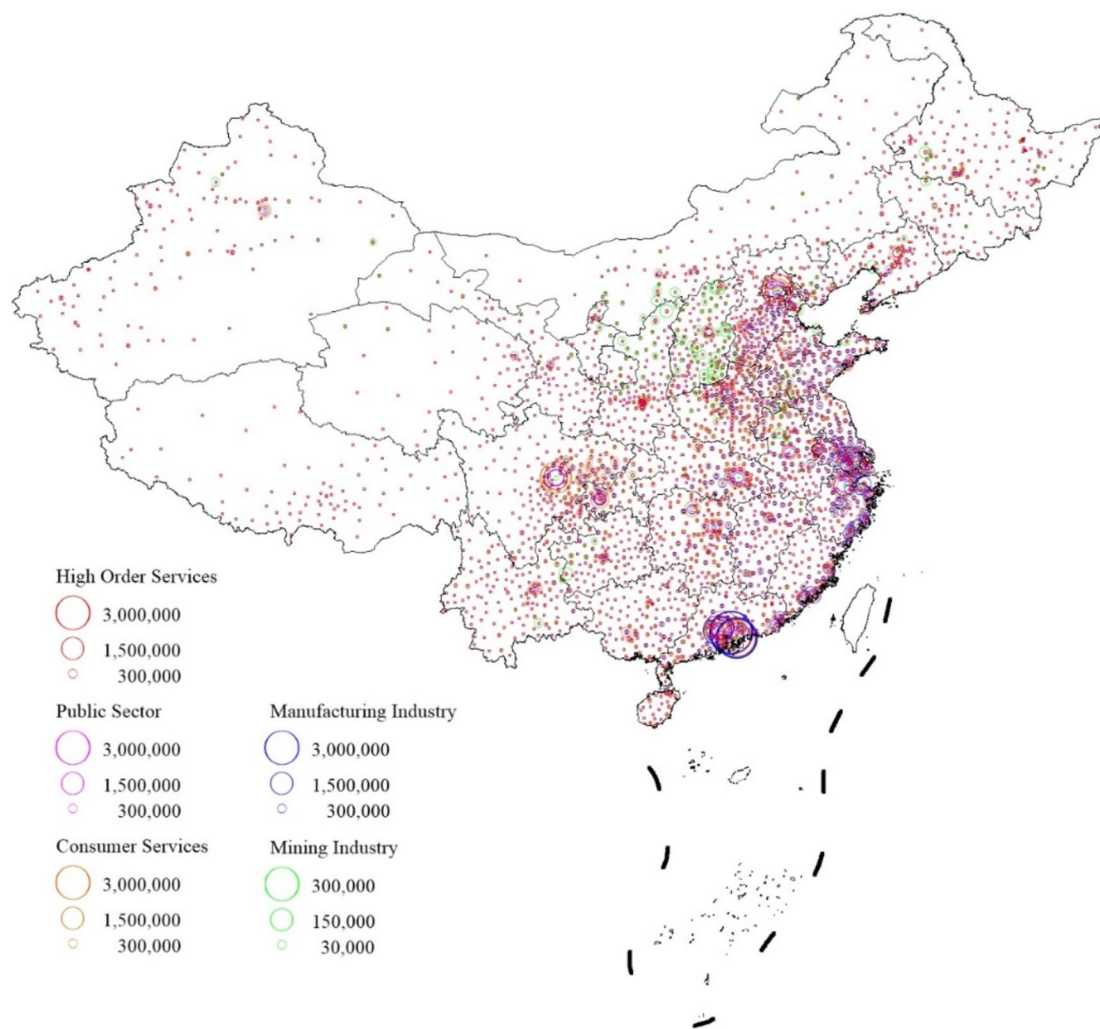


Fig. 3 Functional Specialization based on Typical Sectors

Ningxia along Yellow River area only has 0.20 million. At the same time, compared to those developed UAs abroad, manufacturing is higher in current China’s UAs. In 2020, the regions with the highest employment in manufacturing were the Yangtze River Delta and Pearl River Delta regions, with a total amount of over 15 million, the third largest is the coast of Zhejiang-Fujian-Guangdong. Overall, the manufacturing of regions in East coastal areas is still very crucial, and UAs in the South China are significantly ahead of those in the North. And the manufacturing employment of UAs in the Yangtze River Basin Belt is also far more advanced to other regions.

3 Paradigm shifts and changes of China’s UAs

3.1 Evolution and the two paradigm shifts of China’s UAs

The development of UAs in China has gone through a tortuous process. Before 1978, under the background of the planned economy system in which the development

of the manufacturing industry was a priority, the UAs mainly included Beijing-Tianjin-Tang region, central and south Liaoning region, Harbin-Daqing- Qiqihar region, the Yangtze River basin. In some places with particular location or production factors, such as Chengdu-Deyang-Mianyang region, Central Guizhou region, there were also some progress in UAs development.

The reform and opening up in 1978 established the first paradigm shift milestone. The marketization mechanism and globalization process gradually became key driving forces for reshaping China’s UAs. Both in terms of growth speed and driving force, China’s UAs were completely different from the previous stage. The UAs driven by the planned economy have undergone profound transformation, and even sharp shrinkage, especially in the Northeast. While the Pearl River Delta took the lead in rapid rise, followed by the Yangtze River Delta area and the coordinated development of the Beijing-Tianjin-Hebei

Table 3 Principal component analysis of county-level units based on FURs and agglomeration

Factors	Agglomeration of High end service	Functions of High end service	Functions of Public sectors	Functions of Mining	Agglomeration & Functions of manufacturing	Agglomeration & Functions of International Organization	Agglomeration of Mining	Agglomeration of Primary industries	Functions of Water management
Density	0.03	-0.05	-0.17	-0.03	-0.10	-0.01	0.05	0.89	0.02
Agriculture, forestry, animal husbandry and fishery	0.10	-0.02	0.03	-0.02	0.11	-0.01	0.91	0.04	-0.01
Mining	0.57	0.12	-0.05	-0.11	-0.02	-0.11	0.02	0.01	0.09
Electricity, heat, gas and water production and supply	0.73	0.16	0.25	0.02	0.12	-0.05	0.47	0.11	-0.08
construction	0.86	0.26	0.00	0.12	-0.04	-0.10	0.12	0.15	0.04
Wholesale and retail industry	0.94	0.16	0.04	0.08	0.03	-0.02	-0.01	0.06	0.01
Transportation, storage and postal services	0.92	0.18	0.07	0.07	0.10	-0.02	0.04	0.08	0.00
Accommodation and catering	0.95	0.13	0.01	0.12	0.02	0.06	-0.02	0.03	0.02
Information transmission industry	0.91	0.25	-0.05	-0.02	-0.03	0.12	-0.07	-0.10	0.03
finance	0.93	0.17	0.07	0.03	0.02	0.18	-0.02	-0.04	-0.03
real estate	0.96	0.21	0.01	0.05	0.01	0.08	-0.04	-0.04	0.02
Leasing and Business	0.93	0.20	-0.01	0.04	0.01	0.19	-0.01	-0.05	0.02
Scientific research industry	0.91	0.27	0.03	-0.03	-0.02	0.15	-0.01	-0.08	-0.01
Water conservancy and environmental industry	0.93	0.23	0.06	0.05	0.04	0.09	0.07	0.02	0.03
Residential service industry	0.95	0.17	0.02	0.11	0.04	0.03	-0.02	0.05	0.02
Education industry	0.91	0.26	0.13	0.01	0.01	-0.01	0.08	0.04	-0.03

Table 3 (continued)

Factors	Agglomeration of High end service	Functions of High end service	Functions of Public sectors	Functions of Services	Functions of Mining	Agglomeration & Functions of manufacturing	Agglomeration & Functions of International Organization	Agglomeration of Mining	Agglomeration of Primary Industries	Functions of Water management
Health and Social Work Industry	0.94	0.16	0.14	0.05	0.04	0.00	0.09	0.08	0.03	-0.05
Culture, sports and entertainment	0.92	0.22	0.04	0.03	-0.01	-0.03	0.24	-0.02	-0.05	-0.01
Public management industry	0.88	0.21	0.21	0.03	0.05	0.03	0.08	0.13	0.07	-0.07
International Organization Industry	0.54	0.02	-0.03	0.03	0.00	-0.06	0.70	-0.07	-0.08	-0.02
Agriculture, forestry, animal husbandry and fishery	-0.20	-0.53	-0.18	-0.46	-0.22	-0.54	-0.02	-0.11	0.09	-0.11
Mining	-0.06	-0.03	-0.18	-0.11	0.68	-0.18	0.02	0.35	-0.23	0.12
manufacturing	-0.04	0.07	-0.24	-0.03	-0.05	0.91	0.01	0.00	0.00	-0.06
Electricity, heat, gas and water production and supply	-0.02	0.09	0.44	0.01	0.67	-0.01	-0.01	0.14	-0.12	-0.01
construction	-0.15	0.00	-0.17	0.61	-0.47	0.00	-0.03	0.21	-0.13	0.00
Wholesale and retail industry	0.26	0.47	0.02	0.45	0.10	0.37	-0.07	-0.06	0.25	-0.14
Transportation, storage and postal services	0.06	0.22	0.09	0.31	0.67	0.13	-0.03	-0.09	0.08	0.03
Accommodation and catering	0.15	0.11	0.19	0.70	0.04	-0.12	-0.03	-0.06	-0.10	0.15
Information transmission industry	0.54	0.72	0.03	0.00	-0.01	0.03	0.04	-0.05	-0.09	0.04
finance	0.53	0.60	0.38	0.10	0.23	0.04	0.07	-0.02	0.01	-0.08
real estate	0.39	0.74	0.07	0.24	0.11	0.17	-0.02	-0.01	0.05	0.02
Leasing and Business	0.38	0.73	0.07	0.16	0.06	0.07	0.17	0.03	0.02	0.06
Scientific research industry	0.47	0.80	0.12	-0.04	0.04	0.04	0.05	0.02	-0.05	0.05

Table 3 (continued)

Factors	Agglomeration of High end service	Functions of High end service	Functions of Public sectors	Functions of Services	Functions of Mining	Agglomeration & Functions of manufacturing	Agglomeration & Functions of International Organization	Agglomeration of Mining	Agglomeration of Primary industries	Functions of Water management
Water conservancy and environmental industry	-0.01	0.09	0.17	0.04	0.07	-0.01	0.03	-0.01	0.02	0.91
Residential service industry	0.09	0.28	-0.07	0.62	0.27	0.08	0.04	-0.09	0.17	-0.13
Education industry	0.15	0.43	0.72	0.07	0.05	-0.08	-0.05	0.03	-0.04	0.03
Health and Social Work Industry	0.32	0.40	0.68	0.16	0.23	-0.08	0.01	0.05	0.03	-0.04
Culture, sports and entertainment	0.41	0.64	0.27	0.19	0.04	-0.01	0.14	-0.01	-0.06	0.07
Public management industry	-0.06	-0.09	0.75	-0.09	0.03	-0.16	0.08	-0.02	-0.22	0.31
International Organization Industry	0.17	0.14	0.05	-0.05	-0.01	0.00	0.86	0.02	0.03	0.04

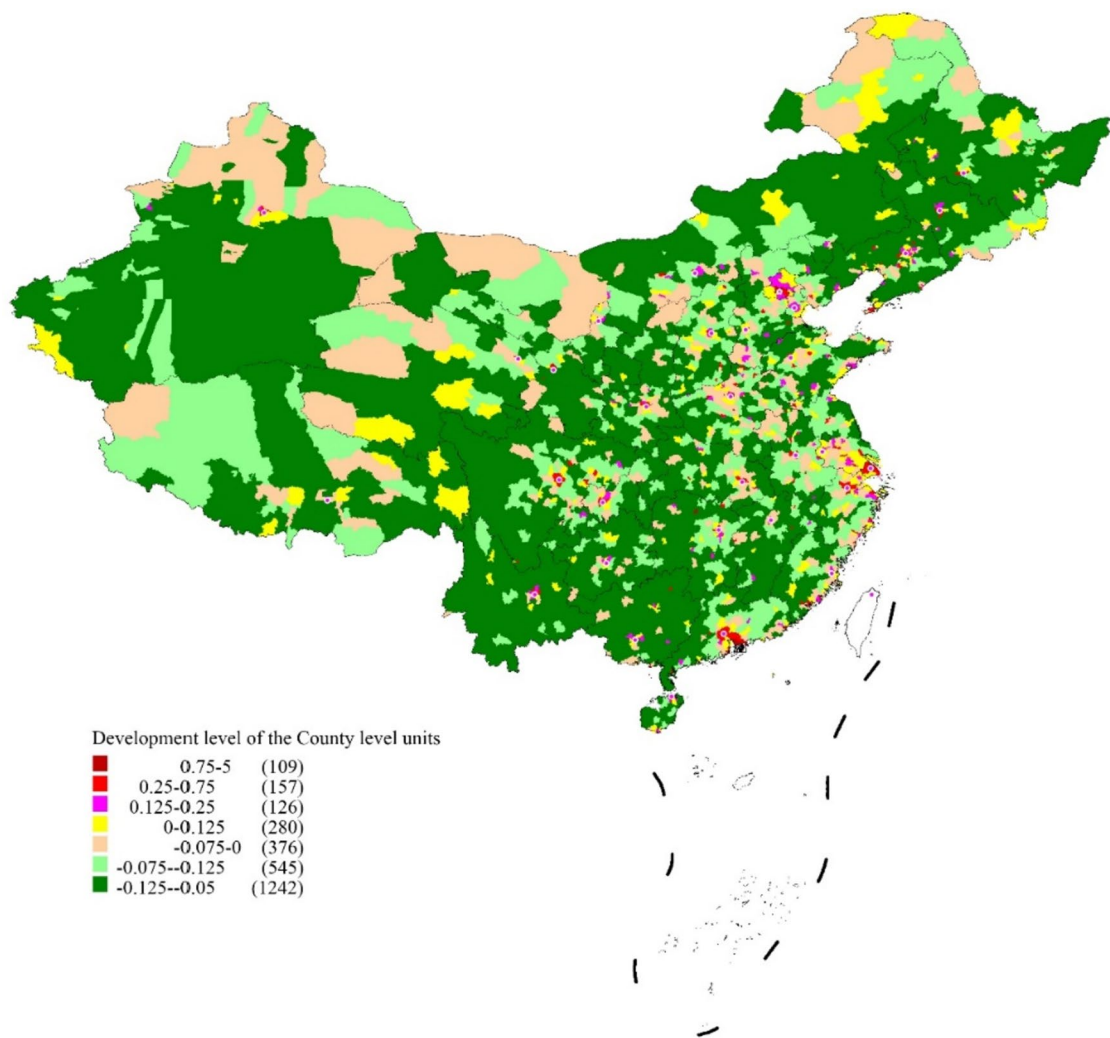


Fig. 4 Development Level of China's County-level Cities

region. Under the dual effects of the state led and the market forces, UAs in the Middle and West regions, such as the Chengdu-Chongqing region, undergone a continuously growth and development.

In 2005, another paradigm shift was initiated, and for the first time the "11th Five Year Plan" proposed "UAs should be the main form of urbanization". With the increasing contradictions between population, resource, and environment and global competition, China entered a new development stage with mega cities and urban agglomerations as the most important engines. Before 11th Five Year Plan, the national urban development policy continuously focused on "strictly controlling the development of large cities and actively developing small and medium-sized cities"; In the early stages of reform and opening up, small and medium-sized towns played an irreplaceable role in industrialization and made significant contributions to the rural surplus labor. With the

process of marketization and globalization, as well as the diminishing marginal effects, the disadvantages of small and medium-sized cities in terms of economies of scale and agglomeration are becoming increasingly prominent especially with the advantages of mega cities.

3.2 The agglomeration and function changes of China's UAs

3.2.1 Further agglomeration of production factors

From analysis of the population censuses of 2000, 2010, and 2020, mega cities further strengthen the population agglomeration in 2010–2020 compared with 2000–2010. The top 50 fastest population growth cities have a total increase of 93.77 million, with an average growth of nearly 1.9 million per city. While from 2000 to 2010, it was 72.12 million, with an average increase of nearly 1.5 million every year. The population growth of UAs in the east coastal areas is still significant. During 2000–2010,

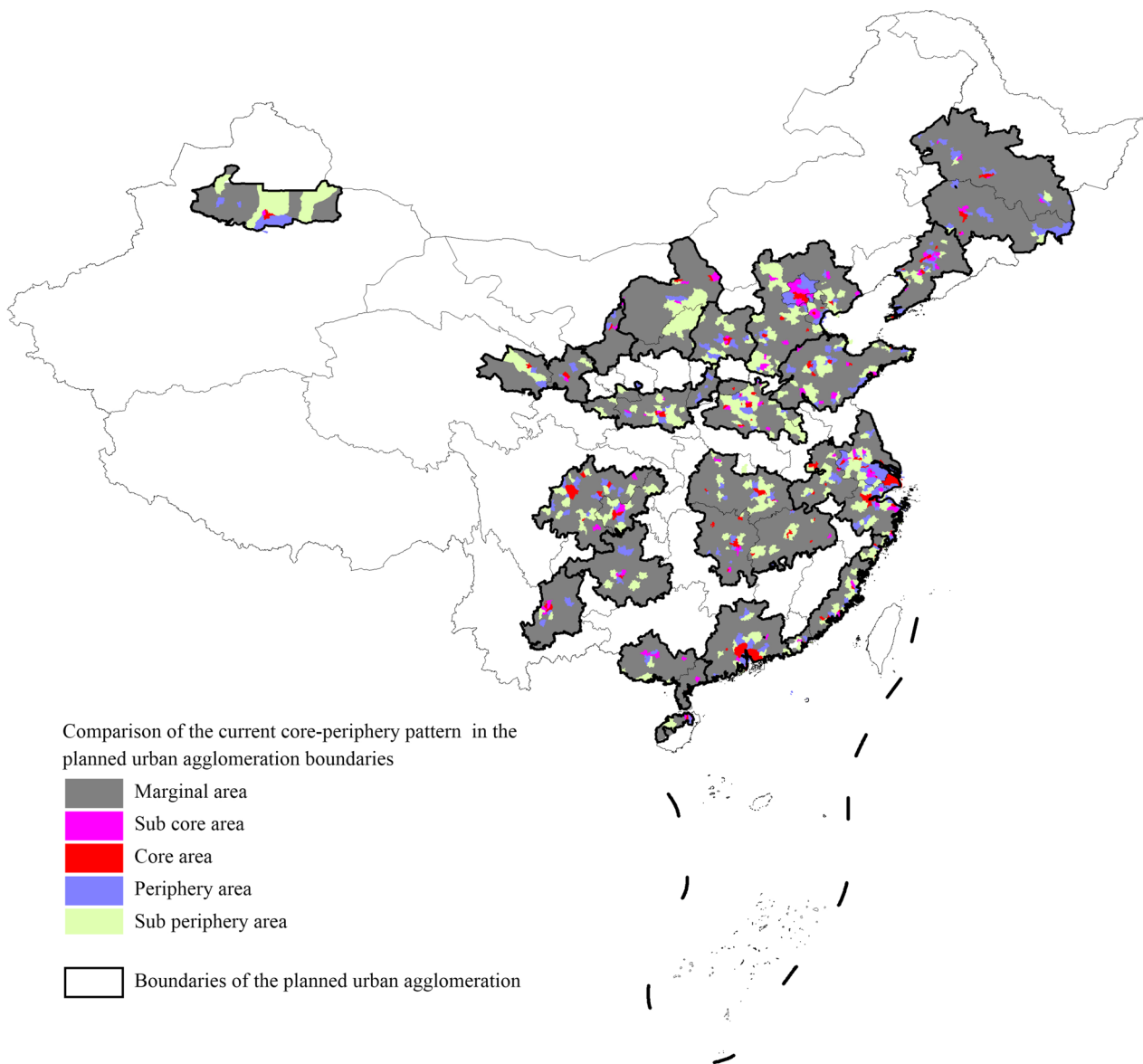


Fig. 5 Actual Spatial Pattern of 19 UAs from Core-Peripheral Model

the population growth of 13 cities in the Yangtze River Delta region ranked among the top 50, while that from 2010 to 2020 increased to 15, the Pearl River Delta region 10 and 7 respectively. The coastal areas of Fujian and the Shandong Peninsula region maintained about 3 and 4 at each stage. Since 2010, provincial capital cities have become important engines of population growth for UAs. During the period from 2000 to 2010, the total population growth of all provincial capital cities (including municipalities directly under the central government) was 42.19 million, an increase of 18.58% compared to 2000; The total population growth of all provincial capital cities from 2010 to 2020 was 57.92 million, an increase

of 21.51% compared to 2010. Moreover, compared to the period from 2000 to 2010, during the period from 2010 to 2020, more provincial capital cities entered the top 50 in terms of population growth (a total of 24), and 5 new provincial capital cities entered (Chongqing, Nanning, Changchun, Lanzhou, Haikou).

In 2000, the proportion of net inflow population to the total population of all 19 UAs was 6.2, which increased to 10.7% in 2010 and further increased to 14.7% in 2020. However, the 19 UAs are different of population agglomeration. Among them, the most eye-catching area is the Beijing-Tianjin-Hebei region. In 2000, the net inflow of population was 5.4%. In 2010,

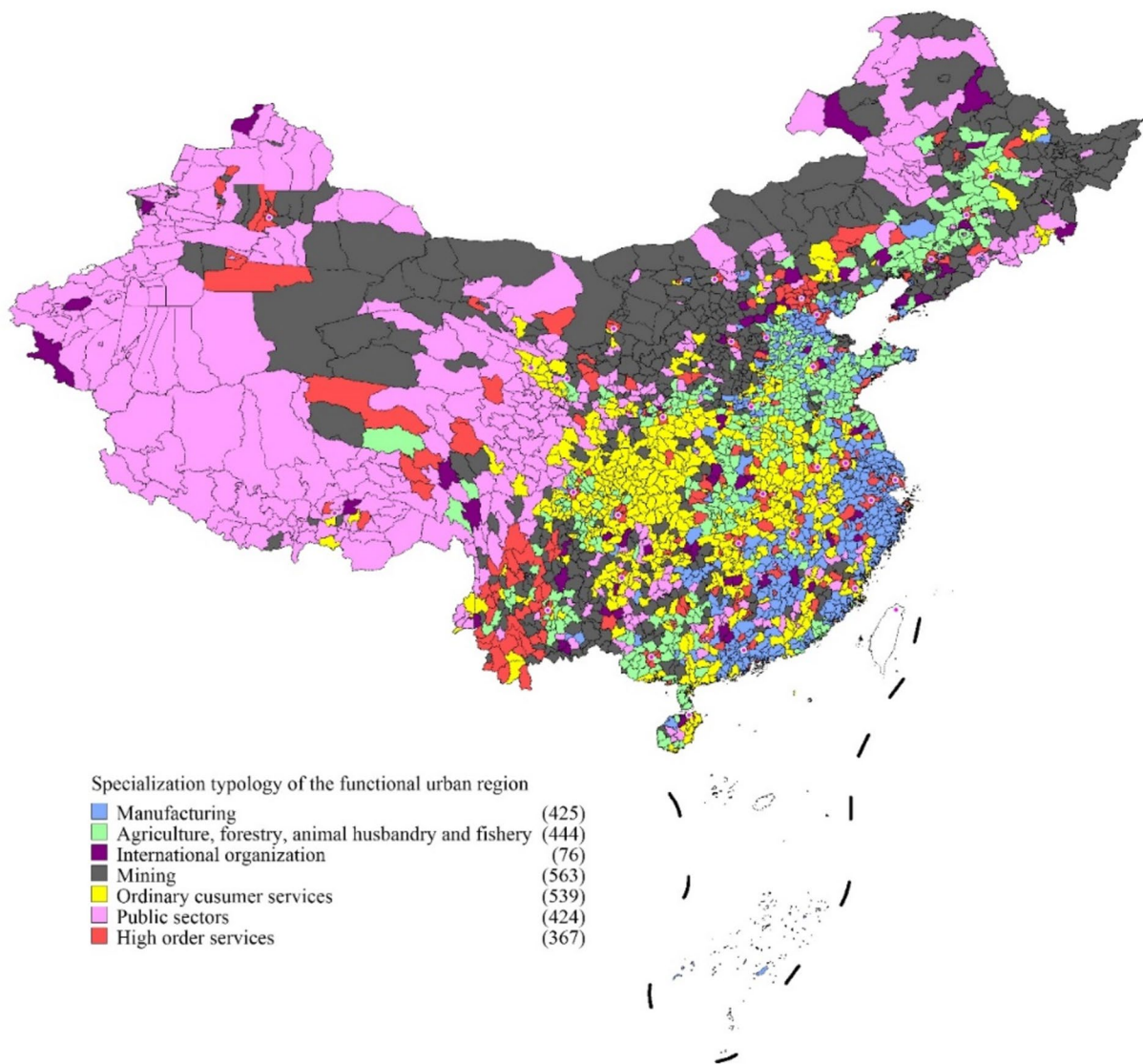


Fig. 6 Functional Specialization Division of China's County-level Cities

it rapidly increased to 15.1%, but in 2020, it decreased to 13.4%. This not only reflects the economic vitality of the region, but also to some extent reflects the effect of the implementation of the regional strategy. Another special area is the Harbin-Changchun region, whose population continues to decline. In addition, the Beibu Gulf area and central Guizhou area are still net outflow areas. In addition some UAs in the Middle and West regions have begun to act as strong regional growth engines. However, the Middle reaches of Yangtze River and the Chengdu-Chongqing region in the Yangtze River Basin have both experienced a sharp change from net population outflow to net population inflow.

Furthermore, we analyze the urban agglomeration changes of human capital, as shown in the Tables 4 and 5. In 2020, the proportion of the population with bachelor's degree or above in 19 UAs reached as high as 10.3%, far higher than the proportion of all prefecture level cities with 7.69%; In terms of the proportion of the population aged 15–64, 19 UAs reached 71.47%, significantly higher than the proportion of all prefecture level cities at 68.57%. From the perspective of growth rate, whether it was between 2000 and 2010 or between 2010 and 2020, the proportion of undergraduate students and above increased significantly in 19 UAs compared to the overall cities; Meanwhile, in terms of labor force population,

Table 4 Population growth and migration changes in different UAs since 2000

	% of net inflow population to the total			Population growth rate		Increase in the proportion of net inflow population to total	
	2000	2010	2020	2000–2010	2010–2020	2000–2010	2010–2020
Beijing-Tianjin-Hebei region	5.4	15.1	13.4	20.8	6.9	9.7	-1.7
Yangtze River Delta region	5.2	14.8	19.7	17.8	12.3	9.6	4.9
Pearl River Delta region	40.1	46.1	48.4	30.9	38.9	6	2.3
Chengdu-Chongqing region	0.5	-7.9	1.1	-1.2	14.5	-8.4	9
Middle reaches of Yangtze River	2.4	-3	4.3	1.2	12.1	-5.4	7.3
Shandong Peninsula region	2.6	6.6	8	8.8	6.4	4	1.5
Guangdong Fujian Zhejiang Coastal region	3.7	7.9	5.6	15.2	8.7	4.2	-2.2
Zhongyuan region	1.8	3.6	9	13.6	23.3	1.8	5.4
Guanzhong Plain region	2.1	1.4	8.2	7.9	14.6	-0.8	6.9
Beibu Gulf region	-5.9	-5.6	-4.6	13.4	21.6	0.4	0.9
Harbin-Changchun	-0.4	2.1	-1.4	6.5	-5.8	2.6	-3.6
Central and Southern Liaoning	4.5	7.5	10.1	8.1	2.9	3	2.6
Central Shanxi region	4.2	7.8	13.9	15.5	13.4	3.5	6.2
Central Guizhou region	-1.3	-11.1	-4.9	1.2	18.2	-9.8	6.2
Central Yunnan region	12.6	13.2	24.3	11.2	22.6	0.6	11.1
Huhhot-Baotou-Ordos-Yulin region	11	20.4	22.5	23.9	11.4	9.3	2.1
Lanzhou-Xining region	3.8	6	11.8	13.1	13.4	2.2	5.8
Ningxia region along the Yellow River	6	8.5	14.3	25.2	25.1	2.6	5.8
North slope region of Tianshan Mountains	26.9	34.4	41.3	38.3	29.7	7.5	6.9
Total of UAs	6.2	10.7	14.7	13.6	13.5	4.5	4
Total of all prefecture level cities	-	-	-	7.4	5.9	-	-

from 2000 to 2010, all cities showed significant proportional growth, but UAs growth was more significant. During the period from 2010 to 2020, all cities showed significant negative growth, but the reduction in UAs was relatively small.

3.2.2 Functional evolution: the progress of high end service sectors

Due to the change of census standards, only the functional evolution of UAs from 2010 to 2020 is analyzed, which is also the period when the global economic crisis since 2008 has the most severe impact on UAs development. Firstly, overall, the employment growth rates of the 19 UAs and their respective sectors are relatively lower than the national average. From the perspective of various UAs, the growth rate of high-end service in developed regions such as Beijing-Tianjin-Hebei still maintains a high level, but the growth rate in the Middle and West regions is much higher. The vast majority of UAs, such as manufacturing and mining, have experienced significant decrease, but some very important areas in the Middle and West regions, especially the Chengdu-Chongqing region, the Zhongyuan region, and the Middle reaches of the Yangtze River, have experienced rapid growth in

manufacturing. From the perspective of location quotient, all 19 UAs have shown a certain degree of specialization in the non-agricultural employment industry, especially in the high-end service. However, the 19 UAs exhibit diversified change, as shown in Table 6.

3.2.3 Efficiency and resilience of economic performance

During the global economic crisis, efficiency and resilience have been more and more prominent indicators of UAs. For efficiency, the economic development of China's UAs has fluctuated due to national macroeconomic intervention and market regulation. Since 2010, the proportion of GDP of all 19 UAs in the country has decreased first and then increased. Under the influence of the country's 4 trillion yuan investment and other factors, regional economic development significantly converged between 2010 and 2014. After the supply side reform, the market mechanism played key roles in accelerating the economic development of urban agglomeration, and its proportion in the country rose from 63.6% in 2014 to 66.9% in 2021. Urban agglomeration has prominent advantages in economic restructuring and increasing Returns to scale. In addition to the significant decline in the proportion of Beijing-Tianjin-Hebei region, Huhhot-Baotou-Ordos-Yulin

Table 5 Comparison of the proportion and changes of human capital in different UAs since 2000

	2020		Growth rates in 2000–2010%		Growth rates in 2010–2020%	
	% of undergraduate and above	% of population aged 15–64	undergraduate and above	population aged 15–64	undergraduate and above	population aged 15–64
Beijing-Tianjin-Hebei region	14.81	70.53	5.56	5.43	5.81	-8.21
Yangtze River Delta region	11.27	71.92	4.03	4.84	5.32	-5.99
Pearl River Delta region	9.71	78.08	3.48	3.56	4.31	-4.63
Chengdu-Chongqing region	8.56	68.63	3	2.44	4.3	-5.04
Middle reaches of Yangtze River	11.53	70.48	4.5	6.95	4.51	-7.31
Shandong Peninsula region	8.33	68.65	3.11	3.44	3.87	-7.27
Guangdong Fujian Zhejiang Coastal region	6	69.88	2.13	6.95	2.99	-5.82
Zhongyuan region	9.58	68.38	2.69	5.61	5.08	-5.28
Guanzhong Plain region	11.44	71.03	3.44	7.5	5.36	-6.57
Beibu Gulf region	6.52	65.98	2.11	5.84	3.25	-3.93
Harbin-Changchun	10.3	73.8	3.81	4.33	4.04	-6.15
Central and Southern Liaoning	9.78	71.93	4.44	3.8	2.4	-7.14
Central Shanxi region	12.98	72.42	4.12	5.3	6.25	-4.35
Central Guizhou region	7.66	67.16	2.49	3.6	3.91	-2.26
Central Yunnan region	11.17	73.83	3.78	2.36	4.94	-1.32
Huhhot-Baotou-Ordos-Yulin region	12.93	73.3	4.47	4.56	6.12	-5.35
Lanzhou-Xining region	12.39	72.77	5.02	3.81	4.6	-3.26
Ningxia region along the Yellow River	9.9	71.56	3.07	4.09	5	-3
North slope region of Tianshan Mountains	14.44	76.26	5.78	0.1	3.77	-1.91
Total of UAs	10.3	71.47	3.74	4.82	4.55	-5.74
Total of all prefecture level cities	7.59	68.57	2.6	4.48	3.74	-6.1

region, Harbin-Changchun region, most other UAs have seen steady development and even significant growth, especially in Chengdu-Chongqing region and Shandong Peninsula region. At the same time, the share of Yangtze River Delta and the Pearl River Delta in the national GDP is as strong as ever. Further verification can be made by measuring the proportion of fiscal revenue to GDP. From fiscal risk and economic resilience, since 2010, cities across the country have experienced a continuous increase in fiscal debt levels. However, the deficit rate of 19 UAs is much lower than that of non UAs cities. From individual UAs, the fiscal deficit rates of the Yangtze River Delta and Pearl River Delta are much lower than others in the Middle, West, and Northeastern regions.

3.2.4 Investment or innovation driven: dynamic changes in China’s UAs

From the perspective of the proportion of fixed assets investment in the country, since 2008, the investment drive of urban agglomeration has begun to decline. In 2007, the proportion of fixed assets investment of all UAs in the country was 63.7%, and by 2016 it had dropped to 56.0%. On the whole, China’s urban agglomeration has begun to break away from the investment driven stage.

However, UAs in West China, such as Chengdu-Chongqing region, Guanzhong Plain region, central Guizhou region, and Beibu Gulf region, all start the strong investment driven process. At the same time, UAs show significant turning of innovation driven transformation in terms of innovation capabilities and R&D investment. For innovation capability, several UAs in the Pearl River Delta region, the Yangtze River Delta region, the Beijing-Tianjin-Hebei region, and the Guanzhong Plain region are more significant; For R&D investment to fiscal expenditure, both the three developed UAs, and the Zhongyuan region, Middle reaches of Yangtze River all have good performances, Table 7.

4 Conclusions and discussion

China’s UAs are not only crucial to tackle with the more and more contradiction between population, resources and environment, but also important for global competition and transformation of economic development mode (Wu, 2013; Wang, 2016; Wu et al., 2020). In the national "14th Five-Year Plan" in 2020, 19 UAs are proposed for the global and domestic strategies. Based on the agglomeration economics nature of UAs, this paper carries out a quantitative analysis of UAs defining, from perspective of

Table 6 Comparison of employment growth rates of typical employment industries in 2010- 2020

	Manufacturing	Mining	High order services	Ordinary consumer services	Public sector	Non-primary employment
Beijing-Tianjin-Hebei region	-17.1	-42.4	130.4	12.4	36.2	19.6
Yangtze River Delta region	-14.5	-52.6	152.8	18.4	45.3	15.3
Pearl River Delta region	-0.3	-1.5	208.4	63.3	79.2	40.2
Chengdu-Chongqing region	25.3	-50	236.2	65.3	90.1	78
Middle reaches of Yangtze River	8.1	-53.5	256	43.7	56	58.1
Shandong Peninsula region	-14.7	-28.5	162.4	27.2	36.5	20.8
Guangdong Fujian Zhejiang Coastal region	-18.4	-61.9	149.8	37.8	47.2	16.9
Zhongyuan region	30.4	-39.2	270.6	82.2	77.3	82
Guanzhong Plain region	-14.7	2.2	216.3	22.6	58.5	38.1
Beibu Gulf region	22.9	-24.1	174.5	58.1	61.9	77.1
Harbin-Changchun	-25.3	-45.5	121.1	12.8	25.7	15
Central and Southern Liaoning	-23.4	-40.4	81.2	-1.6	18.5	1.5
Central Shanxi region	-18.2	-8	138.4	10.4	30.9	18.3
Central Guizhou region	12.8	-26.2	234.2	70.3	81.5	81.8
Central Yunnan region	13.5	-34.1	182	78	58.9	73.9
Huhhot-Baotou-Ordos-Yulin region	-0.2	21	116.4	8.9	55.1	19.2
Lanzhou-Xining region	-10.2	-36	142.6	17.1	43.9	33.3
Ningxia region along the Yellow River	38.2	-3.3	141.3	39.6	70.3	52.2
North slope region of Tianshan Mountains	-29.1	-19	127.3	21.7	73.4	33.3
Total of UAs	-9.1	-31.4	165.7	32.5	51.1	29.6
Total of all prefecture level cities	-2.7	-30.3	178.7	42.9	53.5	39.5

Table 7 Analysis of innovation inputs and outputs of China's UAs

	Innovation outputs					Innovation inputs				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
Beijing-Tianjin-Hebei region	4.1	3.8	4.09	5.09	5.75	3.8	3.9	3.9	3.9	4.1
Yangtze River Delta region	5.5	4.4	4.04	5.53	6.17	4.9	5.1	5.4	5.4	5.6
Pearl River Delta region	4.8	6	6.21	7.84	8.78	7.1	8.9	9	7.1	6.9
Chengdu-Chongqing region	3	3.1	2.6	3.11	3.78	1.7	2.3	2.6	2.5	3.7
Middle reaches of Yangtze River	2.5	2.3	3.52	4.91	4.94	4.8	5.2	5.8	4.8	6.5
Shandong Peninsula region	3	1.8	2.58	3.91	4.59	2.9	3	3.7	2.9	2.9
Guangdong Fujian Zhejiang Coastal region	6.1	4.3	3.63	4.9	4.99	2	2.2	2.4	2.7	2.9
Zhongyuan region	5	3.3	3.16	3.61	4.38	2.1	2.2	3.2	3.7	4.8
Guanzhong Plain region	4.2	3.4	3.51	4.3	5.46	2.7	2.6	1.8	1.2	2.5
Beibu Gulf region	1	1.5	0.91	2.08	2.46	0.9	1	1	0.9	0.9
Harbin-Changchun	2.2	0.8	1.17	2.86	3.56	0.9	0.9	1	0.9	1.1
Central and Southern Liaoning	2	1.6	2.06	2.9	3.57	1.2	1.9	1.6	1.5	1.6
Central Shanxi region	2.2	0.1	1.82	2.77	3.07	2.5	2.8	2.4	3.2	3.4
Central Guizhou region	2.3	2.5	2.14	2.8	2.85	1.8	3.2	2.5	2.4	2.2
Central Yunnan region	2.4	2.4	2.1	2.56	3.34	2.2	2.1	2	2.3	2
Huhhot-Baotou-Ordos-Yulin region	0.9	0.2	0.37	0.37	1.06	0.8	0.9	1.2	1.1	1.1
Lanzhou-Xining region	2.1	1.9	1.88	2.26	3.52	1	0.9	1	1.1	0.9
Ningxia region along the Yellow River	2	1.4	1.6	0.78	3.75	1.7	2.1	2.1	1.7	2.2
North slope region of Tianshan Mountains	1.3	1.4	1.18	1.56	2.33	2	1.5	1.5	1.7	2
Total of UAs	4.1	3.7	3.7	4.91	5.55	3.7	4.2	4.3	4	4.4
Total of all prefecture level cities	3.8	2.9	2.94	3.96	4.52	2.7	3	3.2	3	3.3

FUR hypothesis. The findings show that, China's UAs are unique in development forces, and spatial patterns as well. On the one hand, China's UAs are more state-led, though now, the marketing forces more and more crucial. The designation of 19 UAs in the 14th five year plan is a co-production of central government and local government. China's UAs have been evolved from the early planned economy period to the reform and opening up period, and then to the further development of the Socialist market economy until now. Compared with the UAs in Europe and the United States, the promotion of governments at different levels is an important feature of China's. Many of the UAs are less developed, both in economic performances and in regional integration, central city influences. However most of them are crucial for the future. In addition, the provincial capital cities have become important engines for UAs. On the other hand, unlike other typical UAs abroad, China's UAs are quite unique in functional specialization. Most of the developed UAs are specialized in manufacture, not in producer services, though these regions show a remarkable high-end services oriented shift in 2010–2020.

After the first two paradigm shifts, obviously, China's UAs have opened the prelude to the third paradigm shift since 2015 (Yu, 2016). The underlying driving forces include the global economic crisis, the outbreak of the global COVID-19 in 2019, and the domestic strategic turns of dual circulation and Chinese-style modernization, etc. China's UAs have accumulated a large number of problems, while also taken the new mission as national and regional development engines.

Unlike previous stages, China's urbanization and socio-economic development will be more and more complex and harder to predict. However, for the advantages of agglomeration economics and resilience capacities, China's UAs will inevitably be irreplaceable for resolving the regional and local problems, promoting the transformation process of China's development model, and increasing the global competitiveness. China's UAs have various types for meeting multi goals of the whole country. Therefore, single criteria is not reasonable for spatial intervention and decision-making. Generally speaking, the Aihui-Tengchong Line is of great significance for UAs strategy: the regions west of the Line bear the mission of regional coordination, key resource supply etc. UAs east of the Line have absolute advantages in terms of economy, society, environment, innovation, and high-end service, especially in the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions, and play crucial roles for China's urbanization, economic transformations. In Addition, on the Aihui-Tengchong Line, the Chengdu-Chongqing region has been emerging as the fourth most important UA with national and even global strategic significance.

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