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The challenges of high-quality development in Chinese secondary cities: A typological exploration

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ABSTRACT

The governmental initiative of high-quality development (HQD) marks a shift in the Chinese development paradigm from prioritizing speed to prioritizing quality towards comprehensive goals of economic growth, social vitality, innovation capacity, industrial upgrading, regional cooperation, and green transformation. This initiative is increasingly discussed within the framework of mega-regions, with prior studies demonstrating that they are critical arenas for promoting HQD visions. However, unevenness within mega-regions has become an important limitation to this vision. Namely, significant disparities exist between mega-regional core cities and the smaller neighboring cities in most HQD indicators. This paper conceptualizes these smaller players as secondary cities. Based on this, this paper aims to understand and differentiate the specific challenges of secondary cities facing intra-regional unevenness in the context of HQD. We build an evaluation framework and employ the TOPSIS method to evaluate 34 core cities and 180 secondary cities. Then, we introduce typological thinking to develop a meaningful classification of secondary cities based on the results of these evaluations. K-means clustering analysis identifies five secondary city types with similar profiles. The analysis supports the discussion of the characteristics and challenges of each type and may contribute to policy recommendations for a balanced HQD in mega-regional secondary cities.

1. Introduction

October 2017 witnessed an ideological shift in Chinese development paths, marked by the initiative of high-quality development (HQD). Since then, this initiative has guided Chinese socio-economic growth, industrial transformation, and regional governance (Pan et al., 2021; SCC, 2017). During the 13th Five-Year Plan period (2016-2020), governments, academics, and entrepreneurs debated HQD. It indicates that future Chinese development will no longer focus solely on speed but instead emphasize qualitative improvement. An increasing number of studies have focused on expanding the theory and related concepts (Bei, 2018; Li et al., 2019), selecting evaluation methods (Jiang et al., 2021; Song et al., 2022), and optimizing the implementation roadmaps for specific aspects of HQD (Cui et al., 2023; Xiong et al., 2022). These studies enriched the connotation of "quality" to include economic growth, social vitality, innovation capacity, industrial upgrading, regional cooperation, and green transformation. HQD brings together emerging development concepts under a comprehensive framework to promote coordinated development. For example, green transformation and low carbon are widely emphasized as new requirements for growth, but progress in the real economy should also be achieved through technological innovation, policy support, and multi-level governance (Wang et al., 2021). In summary, HQD encompasses multiple aspects, which are expected to form an efficient, complementary, and coherent system.

Mega-regions (***chengshiqun*** in Chinese), spatial development units consisting of one or two cores and the surrounding smaller cities (Zhang et al., 2020), are of great value in facilitating the implementation of HQD. Mega-regionalization can be understood as establishing networks of cooperation and information exchange, the joint governance of regional crises and challenges, and the agglomeration of socio-economic activities (Liu, 2012; Wu and Zhang, 2007; Yeh and Chen, 2020). Therefore, it adds a new concern: HQD should not focus on each city per se but on the common goals of all regional urban areas. Current studies strongly support this idea, as more scholars use mega-regions as frameworks to refine indicators to monitor the level of HQD (Yin et al., 2021), study specific actions and reflect on governance paths (Fu et al., 2022; Peng et al., 2020), and formulate spatial planning in terms of

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industrial distribution, land use, and environmental protection (Hu et al., 2021; Li et al., 2022). The mega-region concept was first raised in 2005 and specified in the 13th Five-Year Plan as the leading spatial framework of Chinese future urbanization (CNDRC, 2016). It originated from rethinking over-competitive urban relations, which had created a severe unevenness problem (Li and Wu, 2018). Thus, in realizing mega-regions, the authorities encourage regional alliances towards coordinated systems, including mobility of talent and knowledge, complementarity of industrial innovation strengths, and sharing of investment and technology (Harrison and Gu, 2023).

In the last two decades, mega-regions have been increasingly emphasized around the world by both governments and academics for purposes of gathering talent, enhancing productive capacity, and promoting innovation (Florida et al., 2008) in order to compete in the globalized economy (Douglass, 2000). This competitive mindset gave rise to many global "superstar" cities, but also revealed the considerable costs of the single-city success, namely intra-regional unevenness, interpreted here as the development gap between the core cities of a mega-region and the other smaller secondary cities.

Indeed, global investment, branding, infrastructure development, and trade are primarily concentrated in the core cities of mega-regions, and surrounding smaller players often struggle to escape merely absorbing the negative externalities of core city success. For example, when the latter implement industrial upgrading or environmental regulations, low-end economic sectors are often relocated to neighboring secondary cities to ensure that the cores maintain the "sustainable development" label. This is often done in the name of "handouts for more secondary city development opportunities and employment for its residents" (Li and Jonas, 2023; Pendras and Dierwechter, 2022), exploiting the weak position of secondary cities in the regional system.

This uneveness has been investigated through comparisons with core cities, including the low capacity of secondary cities to retain urban functions such as commerce and culture (Cardoso and Meijers, 2016), their low attractiveness of development resources such as foreign direct investment (Crețan et al., 2005; Head and Ries, 1996), and their low political voice in the process of regional integration (Cardoso, 2016). On the other hand, development visions for secondary cities are also studied, such as smart city projects in secondary cities part of polycentric regions (Dragan et al., 2023), city branding to attract investment opportunities (Vesalon and Cretan, 2019), and the potential for metropolization to improve the overall economic, functional and institutional capacity (Cardoso and Meijers, 2017). This has not always been successful, however, as some investments to implement large-scale urban functions, such as university campuses, had little impact because the attractiveness of secondary cities cannot compete with that of the cores (Cetin et al., 2021).

Although not enough attention has been paid to secondary cities in the Chinese context, this literature clearly helps us frame two problems that characterize these cities in China: polarization and peripheralization. On one hand, due to the significant development gaps, there is a unidirectional flow of development resources such as labor, investment, and technology to the core cities (Pang et al., 2023). Since transportation and information exchange channels between core and secondary cities become more intense in mega-regions, polarization is intensified (Huang and Zong, 2021). On the other hand, core cities, as the engines of economic growth of mega-regions, tend to receive preferential policy attention (Li and Jonas, 2023), while secondary cities become peripheralized with a diminishing political voice. In this paper, we count all ordinary prefectural cities in China's 19 mega-regions, other than core cities, as secondary cities.

Existing research on the significant disparities of HQD within regions shows unevenness spread across various fields, including urban resilience (Wang et al., 2021), low carbon transitions (Wang et al., 2021), and overall socio-economic progress (Tian and Wang, 2019). Additionally, the performance of cities within particular mega-regions has been examined to assess the role of mega-regions as drivers of HQD, including ecological well-being (Lan et al., 2022), carbon emissions efficiency (Liu et al., 2018), and social vitality (Jiang et al., 2019). However, three crucial research gaps have not been covered. First, although evaluating the HQD of individual cities provides some evidence of development disparities, this does not focus on the unevenness between core and secondary cities in mega-regions. Therefore, it does not help us further understand polarization and peripheralization problems, as these relate specifically to core-secondary uneven relations. Second, studies of uneveness in individual mega-regions limit the value of the findings for comparability and transferability. Third, there is not enough literature summarizing the characteristics and challenges faced by secondary cities moving towards HQD, as these cities are often not the main focus, and scholars prefer to discuss unevenness at the regional scale.

To summarize, the existing literature reveals the disparity in HQD between core and secondary cities, but it remains unclear in what ways this unevenness unfolds across mega-regions and secondary cities with different characteristics. We aim to answer this question in this paper. To this end, we use a typological approach to classify secondary cities according to their performance gap to core cities in HQD visions. From there, we expect to derive a more nuanced understanding of how intra-regional unevenness takes shape in different types of cities. Building a typology of mega-regional secondary cities for the first time in the Chinese context helps us frame their characteristics in a more structured way and compare their challenges to provide targeted policy recommendations. This is an innovative approach, considering that currently scholars tend to categorize secondary cities roughly as "good performers" or "poor performers" without discussing their underlying features more deeply, which leads to blanket policies that neglect the specific combinations materializing "unevenness" in different places and between core and secondary cities.

We answer this question as follows. First, (Section 2), we review literature and policies related to the HQD initiative and develop an applicable analytical framework that incorporates the features of secondary cities in the context of intra-regional unevenness. In the second step (Section 3), we select representative indicators based on that analytical framework and develop a methodology to explore the characteristics of the performance gap between core and secondary cities. This is achieved through two approaches. We firstly employ the TOPSIS evaluation method to measure the HQD performance of each city. Then, we conduct a K-means clustering analysis based on the performance gap between core and secondary cities to group cities facing similar unevenness conditions and lay the foundation for further discussion of their common challenges. Sections 4 and 5 summarize the different types of secondary cities based on the evaluation and clustering results. In Section 6, we discuss the challenges of secondary cities facing intra-regional unevenness. The paper concludes by elaborating on the policy implications for the HQD of mega-regional secondary cities. By providing a typology-based exploration of Chinese secondary cities in mega-regional systems, we contribute to policy formulation and academic research, and show that the concept of "secondary city" is applicable in China, a context with different spatial scales, governance paradigms, and socio-economic statuses than those of the Global North. This expands the discussion on "secondary cities" globally, and provides an analytical basis to respondg to their challenges.

2. Bringing together HQD and mega-regional secondary cities

2.1. Six aspects of HQD

Existing literature discusses the driving forces, evaluation indicators, and crisis resolution of HQD as a more sustainable development goal compared to past rapid development paths (Bei, 2018; Pan et al., 2021). On this basis, HQD consists of six aspects. First, it remains centered on development, emphasized in the 14th Five-Year Plan (CNDRC, 2021). Despite the increasing focus of authorities on slowing down the speed of development and upgrading its quality, economic progress remains an important consideration (Pan et al., 2021). This is because the expansion of infrastructure, innovative capacity, social welfare, climate change response, and industrial structure upgrading require a strong economy as a foundation. Second, HQD makes social vitality a critical agenda, and people's well-being and social prosperity are recognized as essential indicators for examining the fruits of economic development (Liu et al., 2020). Third, HQD targets innovation as a driving force. As a core factor driving social vitality and economic progress, innovation is widely recognized as an essential reflection of competitiveness (Liu et al., 2021). Fourth, industrial upgrading is a crucial path to HQD. These challenges the traditional high-pollution, high-energy-consumption, and labor-intensive industrial clusters and looks to emerging technologies and industries to facilitate industrial transformation and upgrading (Song et al., 2022). Fifth, openness and regional cooperation are core components of HQD. This promotes a coordinated and well-balanced development pattern to share the development results and emphasizes a just and inclusive development environment based on the free flow of information, investment, and talent (CNDRC, 2021). Sixth, green transformation is a fundamental requirement for HQD. The rapid development of China over the past forty years has come at the cost of environmental pollution and ecological degradation, and authorities have imposed strict regulations on this issue (Chen et al., 2021). Environment, energy, and ecology have become the three-alarm bells in the HQD process.

2.2. Secondary cities in the context of HQD

It must be recognized and seriously considered that the unevenness between cities limits the vision of HQD being achieved by all Chinese cities. The concept of the mega-region helps us to think about this issue. From an industrial upgrading perspective, for example, core cities tend to have stronger economic, innovation, and governance capabilities to optimize their industrial structure. Besides, they also have a concentration of talent, technology, and investment, which is crucial for social vitality and urban innovation. Secondary cities are less fortunate. They need to withstand the loss of talent and investment due to huge attractiveness of the neighboring core while adapting to the new development requirements, balancing economic progress with the multiple tasks of turning city green, open, and improving well-being of its inhabitants.

Despite their multiple challenges, the authorities have not neglected secondary cities but have considered them key players in regional coordination to achieve overall regional HQD. In recent years, mega-regional policies and territorial spatial planning have explicitly envisioned these cities as new targets on their paths to HQD. Regarding development, the size of secondary cities is often expected to expand to rebalance the regional spatial structure. In the Yangtze River Delta, while the core city of Shanghai is strictly regulated for urban construction and expansion, neighboring secondary cities, such as Taizhou, enhance their capacity for population agglomeration by relaxing the restrictions on resident registration and social welfare guarantees (DNR Jiangsu, 2021). This is also related to the economic prospects of secondary cities as they want to attract more high-end industries to optimize the local industrial structure. Constructing new business parks to provide sufficient development space to attract investment is a widely used policy (Zheng et al., 2017). In terms of social vitality, secondary cities are often seen as more livable alternatives to large cities due to their lower social pressure and living costs, and better living environment (Dou and Kuang, 2020; Zhan et al., 2018). Therefore, social vitality is expected to attract talent and investment in secondary cities, offering distinctive cultural activities, a vibrant atmosphere, and welfare benefits. Regarding innovation, core cities are often identified as regional innovation centers, and secondary cities should also benefit from this. For example, in the Beijing-Tianjin-Hebei mega-regional plan, secondary cities such as Baoding and Qinhuangdao, located in the surrounding area of Beijing, are expected to combine the innovative output from the core with their own industries to promote innovation capacity (DNR Hebei, 2021). However, the endogenous innovation capacity of these cities also needs government support to better integrate into the regional innovation network. In terms of industrial structure, a competitive set of industries that complements the strengths of other cities is envisioned (CNDRC, 2021). Regarding cooperative development, integration into regional development networks and open markets is especially necessary in secondary cities. This not only facilitates the exchange of information, technology, and talent among cities but also brings them more development opportunities based on the support of neighboring core cities. Finally, in terms of green transformation, ecological and environmental quality and carbon efficiency are becoming new strengths to support their important role in the regional system (Lu and Campbell, 2009; Rong et al., 2018). These six dimensions of HQD summarize the visions in mega-regional planning and policies for secondary cities and help us to rethink more precisely the unevenness problem in mega-regional systems.

3. Research design

3.1. Evaluation framework to quantify intra-regional unevenness

This paper intends to achieve a two-fold objective. First, to construct for the first time a typology of secondary cities from the perspective of HQD trajectories in mega-regional systems. Second, to use that typological discussion to reveal the characteristics of each type and the challenges it faces, ultimately contributing to policy formulation, implementation, and optimization of mega-regional secondary cities. For this purpose, we consider all the 19 megaregions specified in the 14th Five-Year Plan (CNDRC, 2021). After filtering for practical considerations such as lack of data, we select 180 secondary cities (all at the prefecture-level city scale) as the study object. The mega-regional core cities consist of four municipalities directly under the central government's jurisdiction, the provincial capitals, and the sub-provincial cities, with a total number of 34.

We start by quantifying intra-regional unevenness as the gap between mega-regional secondary cities and core cities in various aspects of HQD. Therefore, we construct an evaluation framework based on the HQD vision set for the secondary cities and develop 18 indicators in the six aspects mentioned earlier: urban size, social vitality, innovation capacity, industrial structure, regional embeddedness, and green transformation. These six aspects build a comprehensive assessment of HQD in Chinese cities, and have been widely used by previous studies (Pan et al., 2021; Song et al., 2022; Yang et al., 2021). However, scholars have not agreed on specific indicators to measure unevenness between core and secondary cities. Therefore, we elaborate on the policy orientations and visions of secondary cities towards the six aspects of HQD to formulate the evaluation framework.

For urban size, besides the traditional indicators of population and economic strength, we use the urban built-up area as a crucial proxy because the available space for urban expansion has become an important development asset for secondary cities to participate in mega-regionalization (Gao et al., 2020; Huo et al., 2020). For social vitality, we use a modified nighttime lighting index to capture daily life vitality, taking advantage of its objectivity and accuracy (Lan et al., 2020; Ortakavak et al., 2020), together with indicators representing cultural and social vitality. For innovation capacity, we include academic papers to evaluate the city's capacity for scientific innovation, considering that patent data can only reflect innovation to a certain extent (Cao et al., 2022), and also consider the governmental expenditure for scientific research (Pan et al., 2021). For industrial structure, we consider the proportion of agriculture, industry, and services in the overall output to determine the characteristics of each city's economy (Song et al., 2022). For regional embeddedness, infrastructure connectivity is often the most important consideration, but to reflect the increasing importance of information flows we also measure informational visibility (Lin et al., 2019). We add an indicator of entrepreneurial cooperation and market openness, as these are key tenets of competitive mega-regions. Finally, we evaluate green transformation in its environmental, ecological, and energy dimension through three proxies: air pollution index (PM 2.5), vegetation quality index (NDVI index), and carbon intensity (Aksoy et al., 2022; Lin and Jiang, 2022; Tang et al., 2021).

By combining existing literature and relevant policies to construct a solid theoretical foundation, collecting the indicators from multiple data sources, including yearbook data, geospatial data, and indexes published by academic institutions, and verifying the accuracy of the indicators through literature in different fields, this evaluation framework is suitable to measure unevenness between core and secondary cities in the HQD perspective. Table 1 shows the indicators, data sources, and related references. We selected the 2020 data for our study because that year is the beginning of the 14th Five-Year Plan, marking a new stage in which mega-regions became the leading carrier of future urbanization in China (CNDRC, 2021).

3.2. Applied methodology: TOPSIS evaluation and K-means clustering analysis

The evaluation framework and the collected data can examine the HQD performance of both core and secondary cities. On this basis, we subtract the secondary cities' performance values from their corresponding core cities to obtain a quantitative description of the observed unevenness. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to calculate the specific performance value of each city in each particular HQD aspect. The purpose of quantifying intra-regional unevenness is to build a typology of secondary cities based on this general condition. That is, some degree of disparity with the core city under the HQD framework is taken as an attribute of the secondary city, and we group cities with similar attributes together to frame their typology using K-means clustering. As a widely used unsupervised cluster analysis method, K-means is increasingly adopted in urban research. For example, Cardoso (2022) has demonstrated its applicability by creating a typology of British secondary cities based on their demographic composition. This method focuses on the attributes of the given data to ensure the maximum difference between different clusters and the maximum similarity of all elements in the same cluster (Xu et al., 2018). K-means requires a pre-determined K's value before clustering, that is, the number of different types we expect to extract. Silhouette coefficients are a reliable method to determine that value (Wang et al., 2017a). After building the secondary city typology, we summarize each cluster's characteristics based on the TOPSIS analysis results. Also, we visualize the results by GIS to observe the spatial distribution of each type in the mega-regional system.

However, focusing only on the evaluation results according to the gap between core and secondary cities is not enough to determine what factors challenge HQD in these cities, considering that mega-regions are dynamic and complex systems (Yeh and Chen, 2020). Therefore, we use the same TOPSIS method to compare these cities' performance in 2011 and 2020, observing their rise or fall in the regional system. We do not focus on these cities' absolute change because, generally, almost all cities should have made considerable progress over ten years. Instead, we are more interested in development trends in the position change of these cities, making TOPSIS a suitable tool because it essentially determines the performance of a city by calculating the distance between the best and worst cases (Chen et al., 2018). This helps us screen which cities are benefiting from the mega-regional system and improving their position and which are being left behind. Accordingly, we once again

Table 1
Evaluation framework and representative indicators of HQD in secondary cities.

Aspects of HQD	Vision for secondary cities	Representative indicators	Code	Data source	Reference
Urban size-Quality of development foundation	Population concentration	Population (total)	POP	Yearbook (NBS, 2012, 2021)	(Pan et al., 2021; Song et al., 2022),
	Economic growth	GDP (total)	GDP	Yearbook (NBS, 2012, 2021)	
	Space for development	Urban built-up area (total)	BUILT	National Land Survey (MNRC, 2022)	(Huo et al., 2020)
Social vitality-Quality of social development	Daily life vitality improvement	Nighttime light strength (annual mean)	NTL	Harvard Dataverse (Wu et al., 2021)	(Lan et al., 2020)
	Cultural vitality progress	Library books (per capita)	LIB	Yearbook (NBS, 2012, 2021)	(Lan et al., 2020)
	Social welfare guarantee	Pension insurance for employee (percentage)	INSUR	Yearbook (NBS, 2012, 2021)	(Lan et al., 2020)
Innovation capacity-Quality of innovative development	Practical innovation	Patents (per capita)	PAT	Collected from CNKI, www.cnki.net	(Pan et al., 2021)
	Scientific innovation	Scientific papers (per capita)	WOS	Collected from Web of Science, www.webofscience.com	(Cao et al., 2022)
	Innovation support	Governmental expenditure for scientific research (per capita)	EXP	Yearbook (NBS, 2012, 2021)	(Pan et al., 2021)
Industrial structure-Quality of industrial development	Primary industries	Primary industrial income (percentage)	PRI	Yearbook (NBS, 2012, 2021)	(Song et al., 2022)
	Secondary industries	Secondary industrial income (percentage)	SEC	Yearbook (NBS, 2012, 2021)	
	Tertiary industries	Tertiary industrial income (percentage)	TER	Yearbook (NBS, 2012, 2021)	
Regional embeddedness-Quality of open development	Infrastructural connection	Regional transportation land use (percentage)	INFRA	National Land Survey (MNRC, 2022)	(Lin et al., 2019)
	Informational visibility	Baidu index (annual mean) *	INFOR	Collected from ***index.baidu.com***	
	Financial inclusion	Financial inclusion index (aggregate)	FINA	Digital Finance Research Center at Peking University (Guo et al., 2020)	(Wang et al., 2022)
Green transformation-Quality of environmental, ecological, and energy efficient development	Environment quality	PM 2.5 (annual mean)	PM2.5	ChinaHighPM2.5 (Wei et al., 2020)	(Lin and Jiang, 2022)
	Ecology quality	NDVI index (annual mean)	NDVI	National Ecosystem Science Data Center (Yang et al., 2019)	
	Energy efficiency	Carbon intensity (annual mean) **	CARB	The Emission Inventories for 290 Chinese Cities (Shan et al., 2022)	(Tang et al., 2021)

Note:
* Due to the effect of covid-19, the Baidu index of Wuhan and some other cities is abnormally high in 2020, so we pick the data of 2019 for the study.
** Carbon intensity data are selected for 2010 (instead of 2011) and 2020 due to limitations in data accessibility.

conduct a K-means clustering analysis to find different trends in secondary cities according to their progress in HQD. This analysis is conducted in R and Python, and the code is available on request.

3.3. TOPSIS to evaluate the city's performance in HQD

TOPSIS measures the distance between the objective performance and the positive and negative ideal values and uses this to represent the evaluation results (Chen et al., 2018). This method was initially used for multidimensional decision-making. The positive and negative ideal solutions are first decided based on considering the total cost, side effects, and other factors (Zhang et al., 2022a). Subsequently, all possible solutions are ranked according to their distance from the best and worst solutions to support decision-making. In recent years, an increasing number of scholars have used this method to evaluate cities in terms of low carbon levels, sustainable development, and innovation capacity (Chen et al., 2020; Chen and Zhang, 2021; Long et al., 2021). The methodology is suitable for evaluating and comparing different aspects of HQD in core and secondary cities and is specified in the multi-step description as follows.

Step 1: We collect data for the developed evaluation framework and obtain a matrix $A = (a_{ij})_{m\times n}$, with 18 indicators on the horizontal axis and 34 core cities and 180 secondary cities on the vertical axis. Here, i=***1, 2, …, m***, represents a list of m cities; j=***1, 2, …, n***, represents a list of n indicators.

$$A = (a_{ij})_{m\times n} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m1} & \dots & a_{mn} \end{pmatrix} \tag{1}$$

Step 2: We determine the positive and negative ideal solution of each indicator. For positive indicators, the maximum value is the best ideal solution and vice versa. In our evaluation framework, the concentration of PM2.5 and carbon intensity (carbon emissions per unit of GDP) are negative indicators, which means that for these two indicators, the smaller the value the closer to the best ideal situation.

Step 3: Since each indicator has a different unit and scale, we normalize this matrix. For positive indicators, we use formula (2). For negative indicators, we use formula (3). The normalized matrix is $B = (b_{ij})_{m\times n}$. Here, i=***1, 2, …, m***, represents a list of m cities; j=***1, 2, …, n***, represents a list of n indicators.

$$b_{ij} = \frac{b_{ij} - minb_{ij}}{maxb_{ij} - minb_{ij}} \quad 1 \le i \le m, 1 \le j \le n \tag{2}$$

$$b_{ij} = \frac{maxb_{ij} - b_{ij}}{maxb_{ij} - minb_{ij}} \quad 1 \le i \le m, 1 \le j \le n \tag{3}$$

$$B = (b_{ij})_{m\times n} = \begin{pmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{m1} & b_{m1} & \dots & b_{mn} \end{pmatrix} \tag{4}$$

Step 4: For the normalized data, in each dimension (evaluation indicator), the maximum value is the positive ideal solution, and the minimum value is the negative ideal solution. We then get two aggregations: V^+ represents the maximum value in the ***jth*** evaluation indicator, and V^- represents the minimum value in the ***jth*** evaluation indicator.

$$V^+ = (V_1^+, V_2^+, \dots, V_n^+) \tag{5}$$

$$V^- = (V_1^-, V_2^-, \dots, V_n^-) \tag{6}$$

Step 5: After determining the positive and negative ideal solutions, we calculate the performance based on the distance from the target value to the ideal solutions. Where V_{ij} represents the normalized value of city i in the ***jth*** evaluation indicator:

Distance from the positive ideal solution:

$$D_{ij}^+ = \sqrt{\left(V_{ij} - V_j^+\right)^2} \tag{7}$$

Distance from the negative ideal solution:

$$D_{ij}^- = \sqrt{\left(V_{ij} - V_j^-\right)^2} \tag{8}$$

TOPSIS-evaluated performance of city i in the ***jth*** evaluation indicator:

$$Performance_{ij} = \frac{D_{ij}^-}{D_{ij}^+ + D_{ij}^-} \tag{9}$$

Finally, we obtain the matrix $C = (Performance_{ij})_{m\times n}$, which represents the results of the evaluation. It is worth noting that we do not expect an overall evaluation result by adding up all the weighted values of each indicator, which is often achieved through the entropy method or expert interviews. Instead, we want to see the performance results for each indicator specifically, in order to conduct the subsequent clustering analysis.

$$C = (Performance_{ij})_{m\times n} = \begin{pmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \dots & \dots & \dots & \dots \\ p_{m1} & p_{m1} & \dots & p_{mn} \end{pmatrix} \tag{10}$$

Step 6: Matrix $C = (Performance_{ij})_{m\times n}$ is the TOPSIS evaluation result. Based on this, we subtract the results of the secondary city $Performance_{ij}$ from the results of the corresponding core cities $Performance_{ij}^{core}$ to obtain matrix $D = (Gap_{ij})_{m\times n}$, which represents the quantified intra-regional unevenness. Using the same methodology, we measure the performance of the secondary cities in the year 2011, $Performance_{ij}^{2011}$, and compare it to the year 2020 to obtain matrix $E = (Trend_{ij})_{m\times n}$, which represents the development trend of a city. Both matrices $D = (Gap_{ij})_{m\times n}$ and $E = (Trend_{ij})_{m\times n}$ support the K-means cluster analysis.

$$Gap_{ij} = Performance_{ij} - Performance_{ij}^{core} \tag{11}$$

$$D = (Gap_{ij})_{m\times n} = \begin{pmatrix} g_{11} & g_{12} & \dots & g_{1n} \\ g_{21} & p_{22} & \dots & g_{2n} \\ \dots & \dots & \dots & \dots \\ g_{m1} & g_{m1} & \dots & g_{mn} \end{pmatrix} \tag{12}$$

$$Trend_{ij} = Performance_{ij} - Performance_{ij}^{2011} \tag{13}$$

$$E = (Trend_{ij})_{m\times n} = \begin{pmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & \dots & t_{2n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m1} & \dots & t_{mn} \end{pmatrix} \tag{14}$$

4. Preliminary exploration of clustering analysis

4.1. Five types of secondary cities

The Silhouette Method is employed to determine the specific value of K in the clustering analysis, that is, the number of potential clusters. Accordingly, we distinguish five secondary city types based on 18 specific indicators of HQD. Although we find a few overlaps upon visualization of the principal component analysis (PCA), the results are promising for distinguishing a typology of secondary cities (Fig. 1). The overlaps are visible because, on one hand, PCA is not used to depict all the city's attributes but rather to obtain a more intuitive visual representation through dimensionality reduction (Reddy et al., 2020), in this case consolidating 18 indicators into 2 dimensions for visualization. In this process, a small partial loss of information is inevitable. On the other hand, cities at the intersection may be characterized by two different

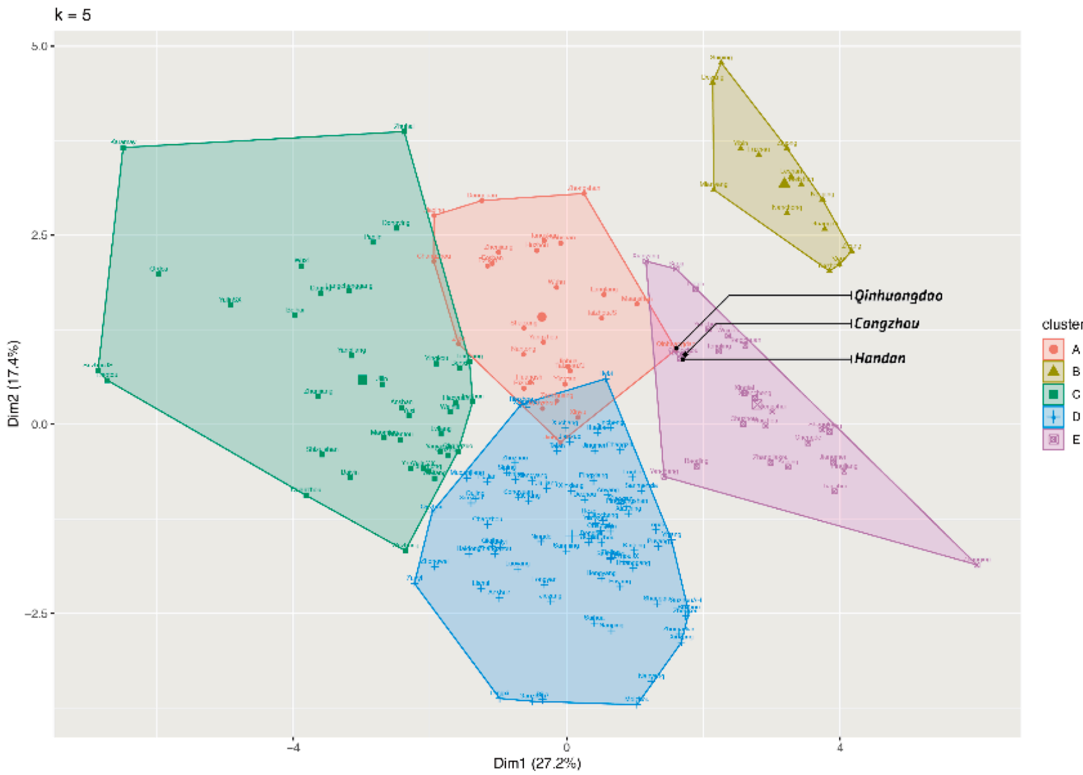


Fig. 1. Clustering analysis results visualized based on the PCA approach.

types simultaneously. For example, Qinhuangdao, categorized as type A, overlaps with type E. The two cities beside it, Cangzhou and Handan, are categorized as type E. However, all three cities belong to the Beijing-Tianjin-Hebei mega-region, and their socio-economic development, industrial structure, and culture are relatively similar. We explore the specific characteristics of each type in the next section and find support for this argument.

Mapping the locations of the different types of cities allows a preliminary observation that, although none of the indicators used determines location, there is some systematic spatial clustering of cities with similar features (Fig. 2). Type A (n=28) is mainly concentrated in the Yangtze River Delta mega-region, the wealthiest part of China. There are also sporadic distributions in the Pearl River Delta and other mega-regions. Cities known for their social vitality and livability are included, such as Zhongshan and Yangzhou (Yi et al., 2021). Smaller cities such as Dongguan and Langfang, which have experienced industrial upgrading in recent years (Li et al., 2020), are also included in this cluster. Type B (n=14) is entirely concentrated in the Chengdu-Chongqing mega-region. These are smaller, less socio-economically developed cities. Type C (n=37) is more concentrated in the Northeast and Western mega-regions, often considered underdeveloped or experiencing industrial difficulties. However, some well-developed cities, such as Suzhou in the Yangtze River Delta, are also categorized in this cluster. Type D (n=76) is the most numerous and is more concentrated in the mega-regions in central China. Type E (n=25) is found on the fringes of the giant mega-regions, where some cities are experiencing difficulties in industrial transformation.

4.2. What distinguishes core cities from secondary cities?

This paper follows regional planning documents to identify core and secondary cities in mega-regions rather than distinguishing between them through quantitative measurements. This results in uncertainty about what specific factors differentiate core cities from secondary cities and where the development gaps lie (Fig. 3). Therefore, we look at the average performance of all core cities and each type of secondary city across the six HQD dimensions to identify their overall differences. Here, we find similarities in the performance of all secondary cities when compared with core cities, allowing us to generalize their respective patterns of difference.

First, core cities significantly outperform secondary cities in size, innovation capacity, and regional embeddedness. The gaps are considerable, especially in economic growth, scientific innovation, and information embeddedness. All the different types of secondary cities perform equally poorly in scientific innovation, which may be an important factor of intra-regional unevenness. As for financial embeddedness, there is a wide disparity among different types of secondary cities. Second, there is not a very large gap between core and secondary cities in the social vitality aspect. The gaps in nighttime light strength and library books are small, which contradicts an initial impression of the difference between busy and vibrant big cities and depressed small cities. Social vitality, thus, may be a potential pathway to repair the weaker position of secondary cities in the regional system. However, nighttime light differences suggest that social vitality varies significantly among different types of secondary cities. Third, core cities are dominated by tertiary industries, while secondary industries characterize most secondary cities. Lastly, core cities do not perform better than secondary cities in all aspects, as illustrated by the quality of the green transformation. We can see that core cities do not perform optimally in any of the three lenses of environment, ecology, and energy and are often surpassed by secondary cities.

These preliminary findings show that, first, focusing on non-core cities in mega-regions and conceptualizing them as secondary cities is necessary in the context of uneven HQD, because all secondary city types are significantly left behind compared to core cities in several aspects. Second, different types of cities have significant variations, suggesting that although they might seem similar compared to the core cities, there are also considerable differences from type to type. The following section discusses how these differences characterize the various types of secondary cities.

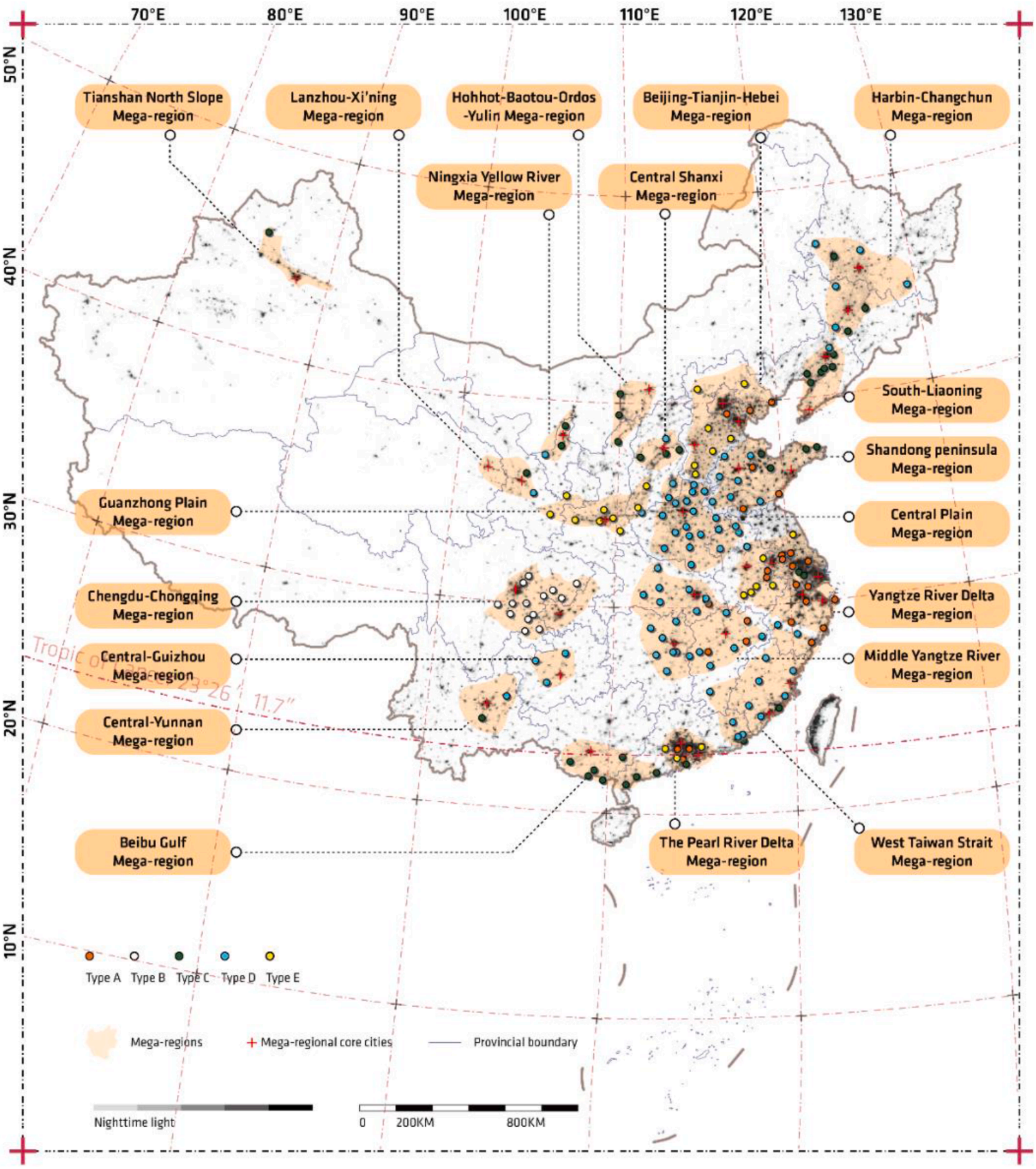


Fig. 2. Spatial distribution of five types of secondary cities.

5. Characterizing different types of secondary cities

The results of the clustering analysis allow us to summarize five secondary city types based on their performance gaps with their core cities in different aspects of HQD. In this section, we focus on the overall features of each type. Accordingly, we named each secondary city type according to their different characteristics (Table 2): (type A) Strong contenders in great mega-regions, (type B) Small players in-between large metropolises, (type C) Pseudo-capitals challenging dominant cores, (type D) Moderate followers, and (type E) Strugglers under the metropolitan shadow. The corresponding data graphics can be accessed in the appendix.

We also find four different development trends in secondary cities according to their progress and regression by comparing the data in the years 2020 and 2011 (Fig. 4). The first trend is most prominent in economic progress, and we find a significant decrease in the proportion of the primary industries and rapid growth in the secondary industries in these cities. The second trend shows the decline of secondary industries and the rapid growth of tertiary industries, with an improved ecological performance. Therefore, these two groups of cities are undergoing industrial transformation and optimization of their economic structure. The third trend corresponds to cities that show a decline: the proportion of primary industries has risen significantly, while other industries face difficulties. These cities are not performing well in size, social vitality, and low carbon-related activities. Secondary cities in the fourth trend show significant improvements in their secondary industrial growth, size, regional embeddedness, and social vitality. Notably, their growth in innovation capacity is superior to other types. However, we also find that their ecological quality has regressed. These four trends provide meaningful insights to define specific challenges of different types of secondary cities in the face of HQD initiatives.

5.1. TYPE-A: strong contenders in great mega-regions

Secondary cities in type A are characterized by a significant gap with their cores regarding urban size, innovation capacity, and regional embeddedness. Spatially, these cities are mainly located in the Yangtze River Delta, including Changzhou and Wenzhou, which are highly developed prefectures (Fig. 5). Here, the gap with the cores reflected in the analysis does not indicate that these cities are lagging behind. On the

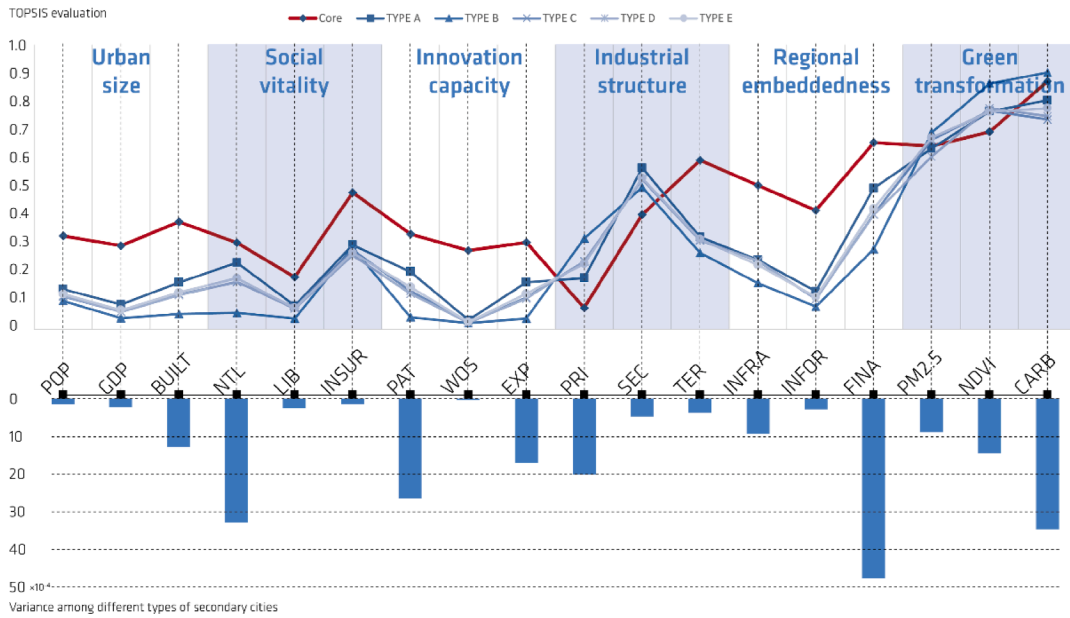


Fig. 3. Compare HQD performance in core and secondary cities.

contrary, the majority of type A outperforms the overall average of secondary cities in all aspects of HQD. The gap is because these cities have the most prosperous cores to compare with: Beijing, Shanghai, Shenzhen, and Guangzhou. Other findings support this argument, such as the social vitality aspect, where there is no significant gap between both. Cities like Dongguan in the Pearl River Delta and Jiaxing in the Yangtze River Delta even have a higher nighttime light index than the cores. A high proportion of secondary industries also characterizes this type. Foshan, adjacent to Guangzhou, has been an important manufacturing base since the 1980s (Tan et al., 2014). These cities have a very low proportion of agricultural output, and their tertiary industry proportion is much lower than in the cores. This suggests that most cities in type A share a complementary economic structure with their cores. In addition, the financial inclusion index of these cities is also higher than other types, indicating that they perform well regarding entrepreneurial and financial activities.

The development trends also confirm that these cities are performing well. Most cities show the fourth trend, meaning they have made significant progress in urban size, innovation capacity, increase of secondary industries, and regional embeddedness (mainly regarding informational visibility) over the past decade. However, some cities in the Shandong and the Beijing-Tianjin-Hebei megaregions show the third trend: a decline in industry, social vitality, and innovation capacity. Tangshan is a famous case for this. Once known for its highly developed coal and steel industries, the city's economic development has suffered a bottleneck in the context of national economic structural optimization and higher demands for environmental quality since the millennium (Xu et al., 2021). This industrial transformation challenge is also reflected in the carbon intensity of Tangshan, which is much lower than others in type A. In summary, although not all cities have made significant progress, they are at the forefront of secondary cities, suggesting a competitive role in mega-regional systems.

5.2. *TYPE-B: small players in-between large metropolises*

Type B cities are only found in the Chengdu-Chongqing mega-region (Fig. 6). These cities are remarkable for the huge gaps in urban size and regional embeddedness, especially in population, urban built-up area, and information visibility. On one hand, these cities are smaller and less visible than most other secondary cities. On the other hand, the cores of this mega-region are two of the largest and most vibrant metropolises in China, with Chongqing as the most populated city with 32 million inhabitants (Zhang et al., 2022b). These two reasons make the urban size disparity the most distinctive feature of type B. In addition, from an industrial structure perspective, these cities have a higher proportion of agriculture than other types and a large gap in the proportion of tertiary industry within their cores.

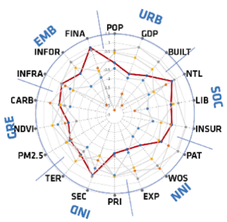
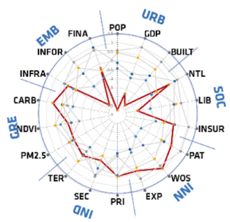
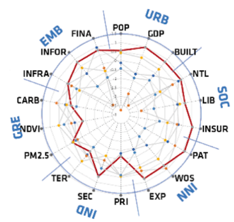
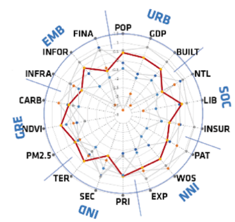
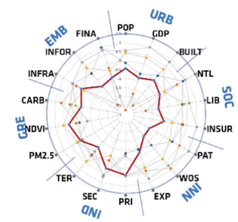
Despite the small size and the large proportion of primary industries implying that this type of city lies at a lower development stage, they do not have a massive gap with their cores in terms of social vitality and innovation capacity. This is not because they perform better in these two aspects, as they are worse than the average of all secondary cities. Rather, Chengdu and Chongqing also underperform in these two aspects, which does not align with their discussed portrait as livable and important hubs for scientific research in Western China (Hou et al., 2023). We believe this is because when processing the data, we chose the demographic averages of the indicators to standardize for the evaluation, and the very large population bases of these two cores result in this phenomenon.

In terms of development trends, the cities of type B are not showing either a decline or a high growth rate, but are undergoing an economic structural transformation. This means that these small players in the mega-regional system are not shrinking because they are sandwiched between two cores casting their metropolitan shadows, but they have not significantly benefited from externalities of the regional network coming from the spillover effects of the cores.

5.3. *TYPE-C: pseudo-capitals challenging dominant cores*

When only considering the HQD gap between secondary cities and their cores, type C cities are the best performers. We name them "pseudo-capitals" because they have a relatively small gap or even outperform their cores in size, social vitality, innovation capacity, and regional embeddedness (Fig. 7). However, when we look at the location and development trends, we see that not all pseudo-capitals perform well in the mega-regional system. On the contrary, most of these cities are in socio-economically backward mega-regions, suggesting a distinction of Type C into two separate subcategories. The first are the truly central secondary cities, such as Suzhou in the Yangtze River Delta, and Quanzhou in the Western Straits mega-region. These cities are very few, but their performance is much higher than average. In regional planning, they often form strong alliances with their cores, such as the

Table 2
Five types of secondary cities.

	TYPE-A	TYPE-B	TYPE-C	TYPE-D	TYPE-E
					
Role in the regional system	**Strong contenders in great mega-regions**	**Small players in-between large metropolises**	**Pseudo-capitals challenging dominant cores**	**Moderate followers**	**Strugglers under the metropolitan shadow**
Urban size	Significant gap with the cores, similar to (but better than) cities in TYPE E	Very large gap with the cores	Small gap with the cores, a few cities larger than the cores	Small gap with the cores	Significant gap with the cores, similar to (but worse than) cities in TYPE A
Social vitality	Small gap with the cores	Large gap with the cores in library books and employee pension, small gap in nighttime light	Small gap with the cores, a few cities better than the cores	Large gap with the cores in nighttime light and employee pension, but small gap in library books	Very large gap with the cores
Innovation capacity	Large gap with the cores	Significant gap with the cores, but only worse than TYPE C	Small gap with the cores, a few cities better than the cores	Significant gap with the cores, slightly worse but similar to TYPE B	Very large gap with the cores
Industrial structure	Low proportion in primary sector, high in secondary sector	Low proportion in secondary sector	Low proportion in primary sector, high in secondary sector	Low proportion in secondary sector, high proportion in tertiary sector	Very low proportion in tertiary sector
Regional embeddedness	Significant gap with the cores, but only worse than TYPE C	Very large gap with cores especially in informational visibility	Small gap with the cores, a few cities better than the cores	Large gap with the cores	Very large gap with the cores especially in informational visibility and financial openness
Environment, ecology, and energy sustainability	Average gap in all aspects	Small gap in carbon intensity Significant gap in ecological conservation (NDVI index)	Large gap in ecological conservation (NDVI index) and carbon intensity	Better than cores in ecological conservation (NDVI index)	Better than the cores in terms of ecological conservation. Large gap in carbon intensity and environmental quality

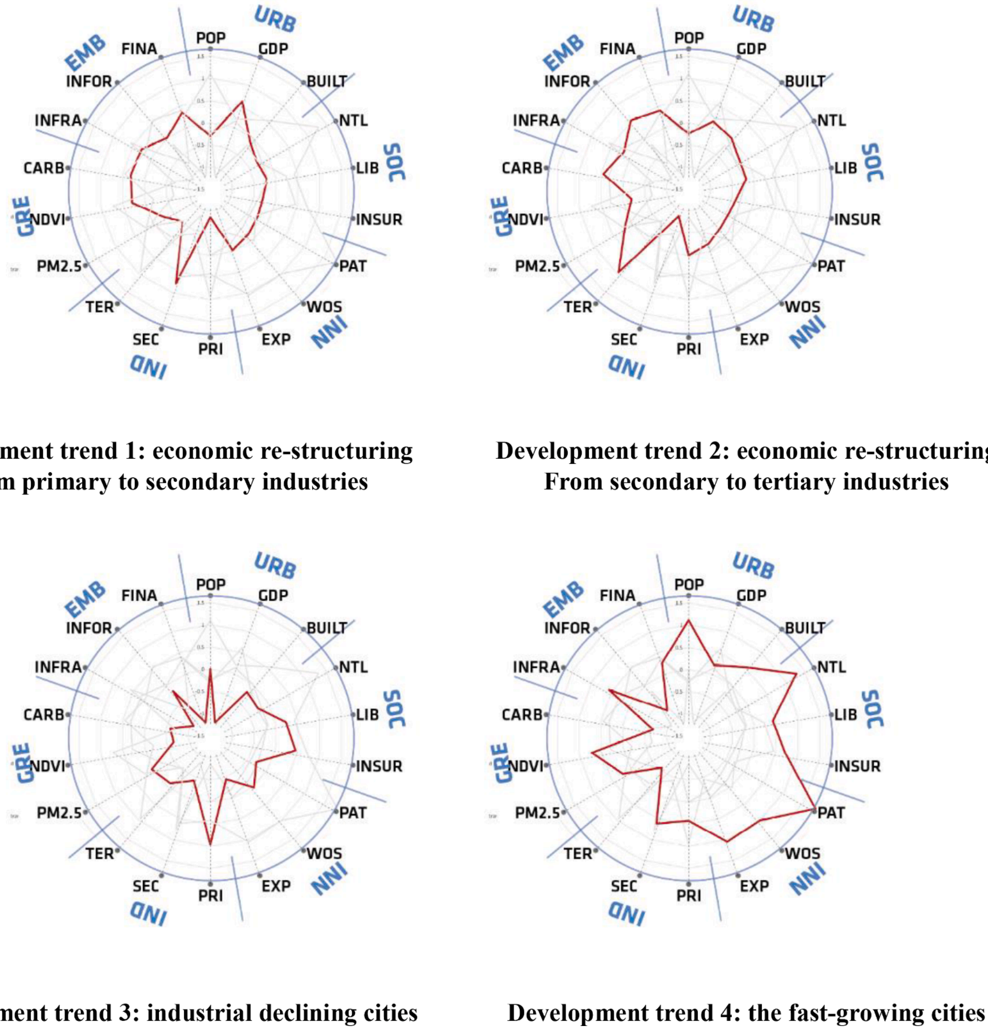


Fig. 4. Four trends of secondary cities' HQD.
Note: URB-urban size; SOC-social vitality; INN-innovation capacity; IND-industrial structure; GRE-green transformation; EMB-regional embeddedness

Shanghai Metropolitan Area and the Xiamen-Zhangzhou-Quanzhou Metropolitan Area (Wang et al., 2020a). They are also expected to play an important role in the region, such as Zhuhai, considered the engine driving the development of the west coast of the Pearl River (He et al., 2021), while the economy of the mega-region is centered on the east coast (Guangzhou-Shenzhen-Hong Kong belt). The second subcategory is mainly located in north China, such as the South Liaoning mega-region. The core cities are not outstanding but have a narrow superiority to maintain their dominant regional roles. This lack of a strong core concerns the authorities: in spatial planning documents, "strong provincial capitals" have often been emphasized as an important development strategy (DNR Liaoning, 2021). Creating a "superstar" city in the region aims to attract more development resources, investment, and talent, and is expected to drive the surrounding secondary cities.

The development trends also show that not all cities play a strong role in regional prosperity. Clearly, the first subcategory, representing a very small part, shows positive development in innovative capacity, social vitality, and secondary industry growth (the fourth trend). However, for the second subcategory, except for the secondary cities in the Beibu Gulf, which are experiencing economic re-structuring (the first and second trends), cities in the north follow the third trend of industrial and socio-economic decline, most having been resource-based and heavy industry cities in the past. HQD initiatives challenge the traditional industries in these cities, and therefore, they face the challenge of transformation towards knowledge-intensive, less carbon-intense, and service-based economic sectors (Wang et al., 2020b).

5.4. TYPE-D: moderate followers

Type D is the cluster with the largest number of cities. We named them Moderate Followers because these secondary cities do not stand out or underperform in any specific aspect, but their core cities perform significantly better in almost all aspects. This "equalization of disparities" allows the core cities to play a dominant role in the mega-region, which has no extreme unevenness problem (Fig. 8). Compared to other types of secondary cities, they have the smallest gap in tertiary industry ratio compared to the cores. This may be because the core cities are also less developed than other mega-regional cores in the high-end service economy, with secondary industries being their mainstay. For example, Wuhan, Changsha, and Nanchang, the cores of the Middle Yangtze River mega-region, and Zhengzhou, the core of the Central Plain mega-region, have higher secondary industry proportions than most other mega-regional cores. Looking at the development trends analysis, most cities in type D are in the first and second trends, showing that they are undergoing economic re-structuring, except for a few cities in the Northeast and Central Plains area, which show a trend of socio-economic and industrial decline. The upgrading of economic structures characterizes type D. It explains why these cities have a smaller gap to core cities in social vitality and perform well in environmental, ecological, and low-carbon aspects compared to other types, with some exploring their

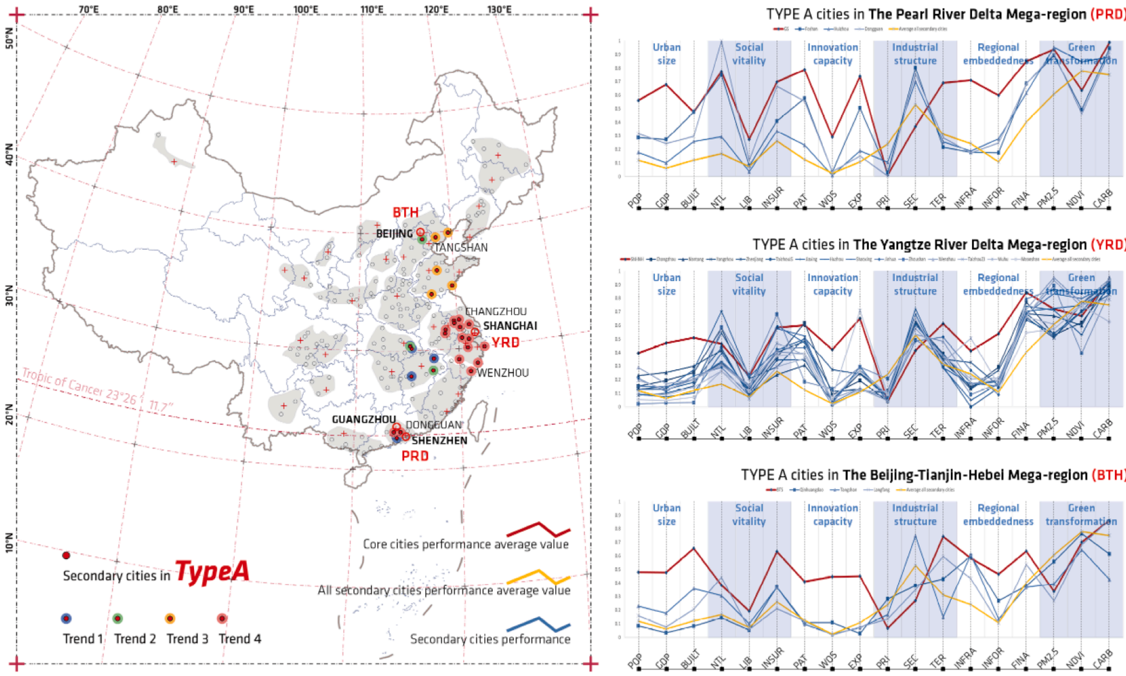


Fig. 5. Profile of Type A.

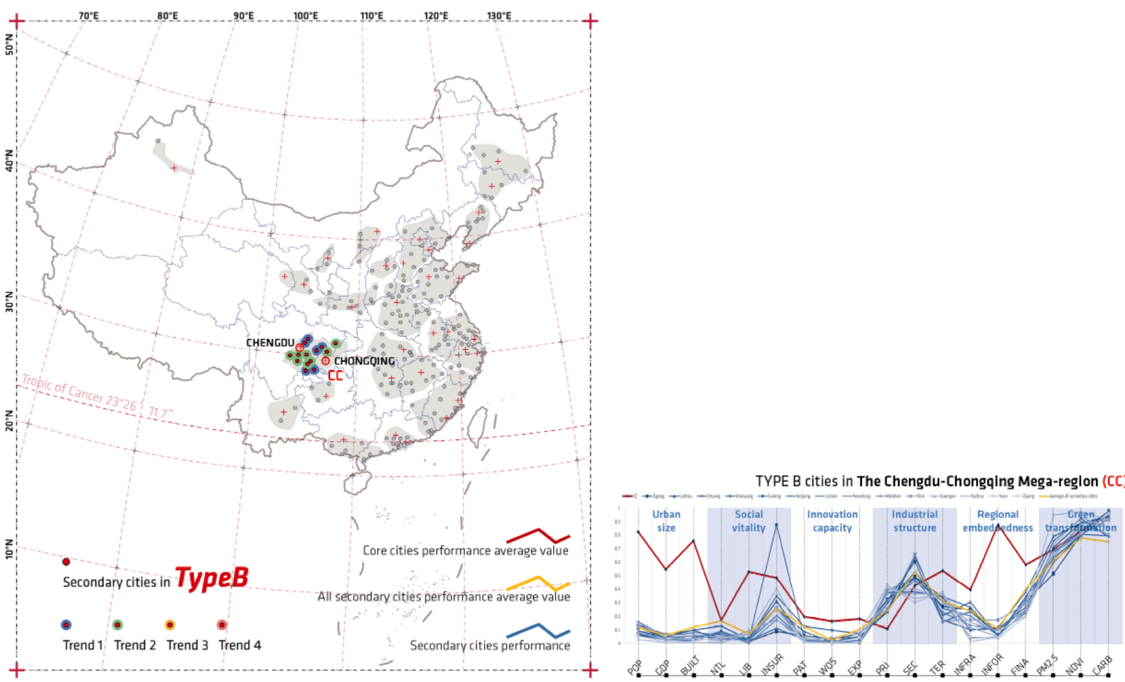


Fig. 6. Profile of Type B.

landscapes and cultural resources to develop tourism after decades of heavy industry-based economic development trajectories, such as Anyang and Luoyang (Kang et al., 2022).

5.5. TYPE-E: strugglers under the metropolitan shadow

Type E cities are significantly disparate from their cores in all aspects of HQD (Fig. 9). Among the five types of secondary cities, the size gap of type E is only lower than that of type B. They also have the largest gap in innovation capacity, social vitality, and regional embeddedness. The performance gap in tertiary industrial proportion and carbon intensity are also larger than in other types, and these cities also perform poorly on the Financial Inclusion Index, a limiting factor in attracting investment and high-end enterprises (Guo et al., 2020). The results suggest that type E cities struggle in the mega-regional system. Spatially, we can see that most cities are in the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta mega-regions, the most developed areas in China. Some are in the Guanzhong mega-region, where Xi'an, the main city of the western part of the country, leads. Struggling to benefit from these mega-regional "superstar cities" is the reason of such a disparity. For example, Zhaoqing in the Pearl River Delta is not well integrated into the emerging regional networks to benefit from social, innovation,

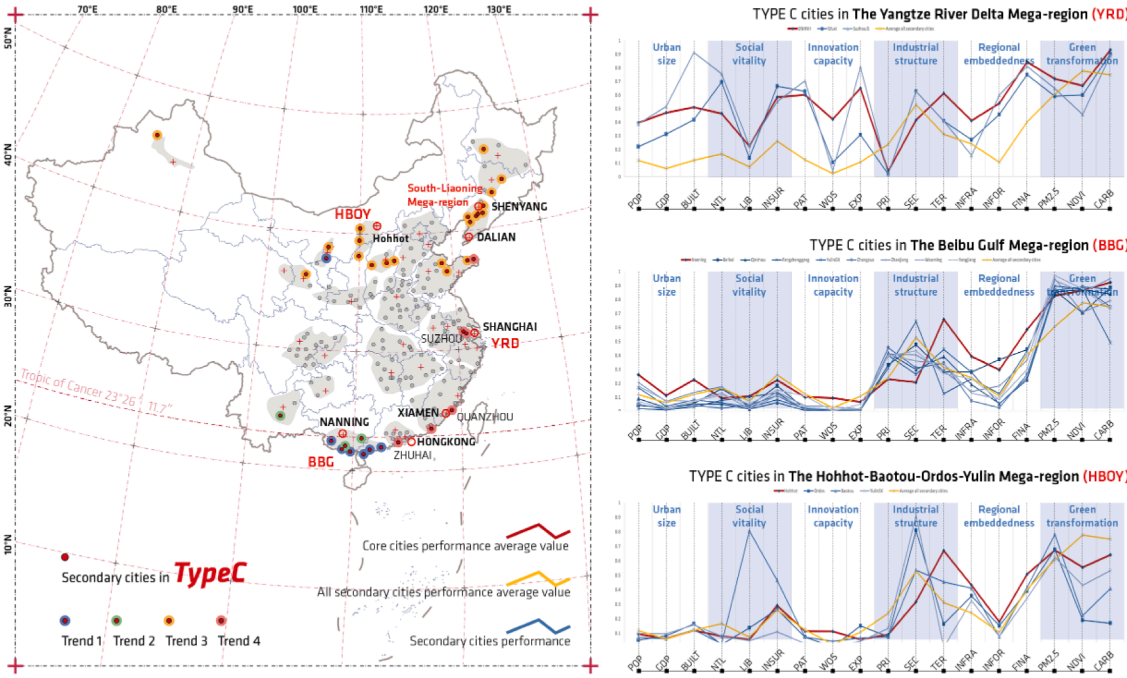


Fig. 7. Profile of Type C.

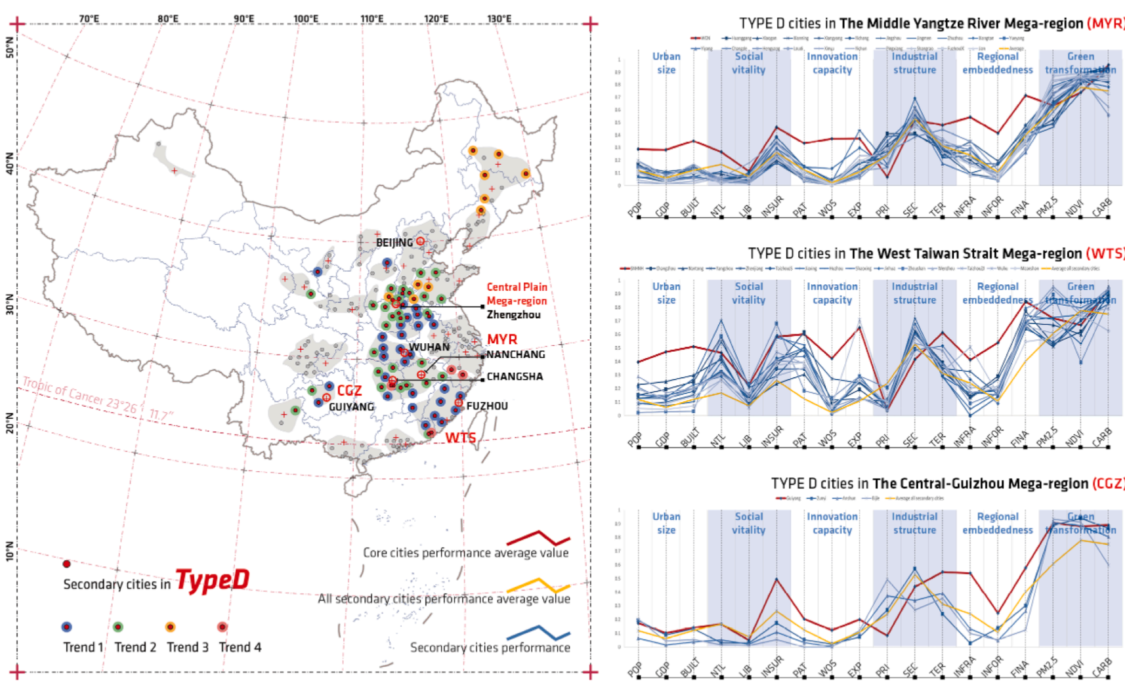


Fig. 8. Profile of Type D.

economic, and industrial externalities (Zhang et al., 2021). In the Yangtze River Delta, type E cities are on the regional periphery, which harms their integration in terms of economic cooperation networks and knowledge and innovation networks (Sun et al., 2022).

Although the gap with the cores is not satisfactory, most cities in type E cities are transforming their economic structure, as shown in the development trends analysis. Zhongshan and Jiangmen, in the Pearl River Delta, even made significant progress in innovation capacity from 2011 to 2020. This indicates that these secondary cities are changing to adapt to the dynamic mega-regional system. However, there are four cities where the situation is worrisome: Handan, Hengshui, and Chengde in the BTH, and Tongling in the YRD belong to the third trend, meaning that their social vitality and industrial development face severe challenges.

6. Discussion

Our findings demonstrate that the concept of "secondary city" based on comparative relations with a core city is significant in the Chinese context. While much international literature has focused on inter-city relations as an essential factor in defining such "secondarity", such a discussion is rare in the Chinese context. What needs to be clarified is

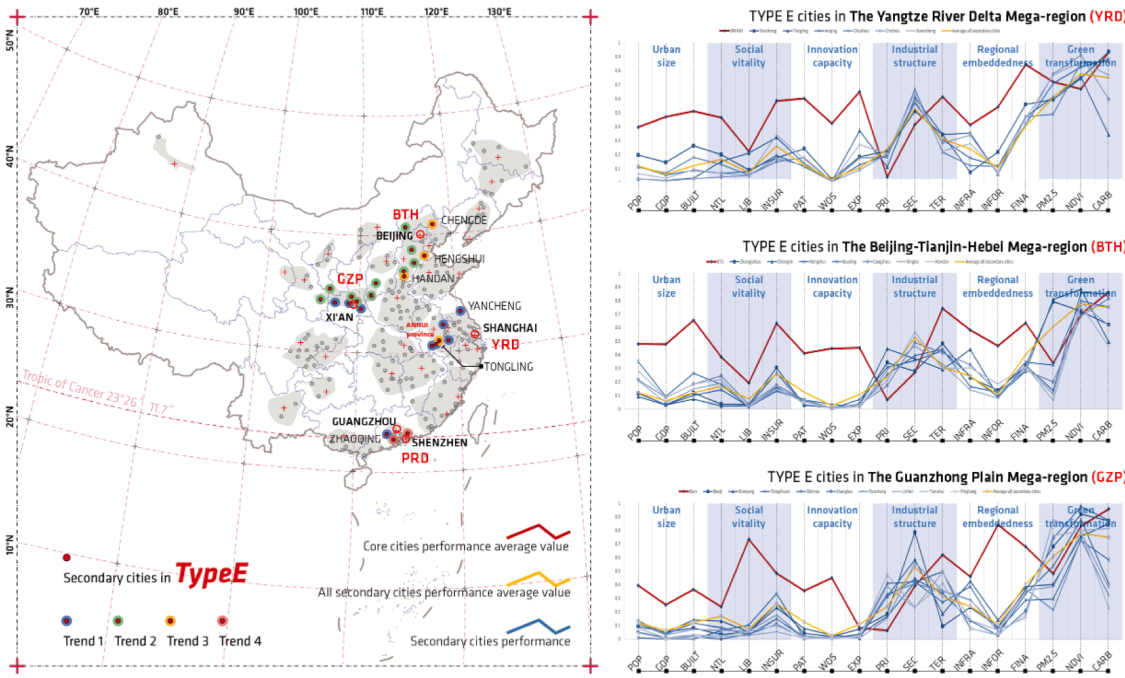


Fig. 9. Profile of Type E.

that these secondary cities are not the widely recognized Chinese "second-tier cities", which are defined on the basis of socio-economic performance and often refer to cities ranked after the four global metropolises of Beijing, Shanghai, Guangzhou, and Shenzhen (Wang et al., 2017b). This paper focuses on mega-regional networks, where "secondary city" is a relational concept. This is a recognized perspective in the international literature, as Pendras and Williams (2021) describe: "By definition, the idea of 'secondary' involves a relationship, a comparison with a dominant other, […] understanding these cities - as well as their dominant neighbours - requires a relational perspective."

Scholars have consistently argued that positive interaction with core cities and a tendency towards spatial integration in polycentric regions contribute to some extent to the socio-economic performance of the secondary cities (Mayer et al., 2021). However, because of different governance contexts, spatial scales, and socio-economic development, this may not be applicable in Chinese secondary cities. For example, "borrowing size", which proposes that secondary cities rely on strong connectivity with the other nearby cities to achieve better socio-economic performance, is a common phenomenon in countries such as the Netherlands (Meijers and Burger, 2017). In Chinese mega-regions, however, the spatial scale of this process may be too large to be effective due to commuting costs and other reasons, failing to realize borrowed size, for example, at the level of regional knowledge and innovation exchange (Yang et al., 2022). Therefore, the specific research needed about the challenges faced by Chinese secondary cities in the uneven relational context of mega-regions may not overlap, but rather complement those of cities in the Global North. For that purpose, we use the previsouly defined typology to outline the specific combination of HQD challenges faced by each type of secondary city.

Type A cities are socially vital contenders in mega-regions with developed cores, such as Shanghai, Beijing, and Shenzhen. However, these cities have significant shortcomings in innovation capacity and a very high proportion of secondary industries, which may indicate their position as absorbers of industrial relocation processes of core cities aiming at sustainability described by Pendras and Dierwechter (2022) for the US case. Such over-reliance on the secondary sector, especially in low-end activities that do not fit core cities any more, can create challenges for their own local sustainability and industrial upgrading, as seen by cities like Tangshan facing a downward development trend (Fig. 4).

One of the challenges faced by type B cities is their low regional embeddedness, particularly informational visibility, which may be due to their small size. This gap poses challenges, e.g., reduced cultural diversity and difficulties in attracting investment. However, core cities with higher visibility also offer opportunities for smaller players to build collaborative networks and expand the regional branding benefits (Lu et al., 2020). Since these cities also perform below average in other aspects, the willingness and capacity of their cores, Chengdu and Chongqing, to support them with industrial upgrading, investment, talent, and policy will be crucial in combating intra-regional unevenness.

Type C cities have the smallest gap with their cores and can even surpass them in HQD. Indeed, developed "pioneer" secondary cities such as Suzhou and Zhuhai are in this type, and have maintained rapid progress in the mega-regional system. The challenge for most other cities in this group is that they are socio-economically declining together with the core cities. Industrial transformation is their biggest challenge, as the resource-based economic model over the past decades has led to a high degree of industrial homogenization, both in secondary cities and the cores. The development paths of post-industrial cities like Shenyang and Harbin have been widely discussed in this regard (Lu et al., 2020). The authorities, however, tend to emphasize their cores: the latest mega-regional spatial plan highlights the leading role of Shenyang and Dalian, and the intention is to concentrate new high-end industries there (DNR Liaoning, 2021).

For type D cities, the findings do not immediately reveal difficulties in the mega-regional system. As noted earlier, these "Moderate followers" are somewhat disparate from their core cities in all aspects, but these disparities are not severe compared to other secondary city types. They also have a higher proportion of tertiary industries than others, suggesting a better chance of standing out in the wave of industrial upgrading. However, the spatial structure of these mega-regions, such as the Middle Yangtze River, the Central Plain, and the West Strait mega-regions, speaks to a problem, as they encompass a wide range of territory. This limits the core city's capacity to positively interact with surrounding secondary cities, and networks of socio-economic activities have not yet been well established. This is why some scholars have argued that these mega-regions are merely "imaginary visions" and have not achieved their potential as a complex and dynamic system (Harrison and Gu, 2021). For example, the Middle Yangtze River mega-region is often considered as three sub-regions led by Wuhan, Changsha, and Nanchang rather than one region with three core cities (Wang et al., 2019).

Finally, type E cities struggle with the toughest challenges. The huge gap between them and their cores in all aspects of HQD indicates their unfavorable position in the mega-regional system. The different fortunes of these cities compared to the other types suggest that the functioning of the mega-regional system is inherently a threat, including the concentration of development resources to the cores, the decrease in political attention, and the inability to adapt to the complexity of the system as it evolves. Notably, most well-performing cities in type A belong to the same mega-regions as Type E: the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin-Hebei. Following the findings by Meijers and Cardoso (2022) about the factors contributing to widely opposing prospects of secondary cities in the Dutch Randstad, the main differences between these two types are worth exploring.

In summary, the different secondary city types in terms of HQD performance and challenges can be interpreted as different types of uneven spatial relations between core and secondary cities. Specifically, type A and type E can be framed within relations between a "superstar" metropolis and the surrounding secondary cities in highly developed mega-regions. Such spatial relations have two-sided consequences and bring very different prospects to secondary cities. Type B represents unbalanced relations framed by a great size disparity. Type C and type D can be seen as mega-regions with less significant gaps between the core and secondary cities, but their relations are tested by, respectively, a common decline trend and the fragmentation resulting from excessive spatial distance.

7. Conclusion

This paper delivers the first typological classification of secondary cities in Chinese mega-regions based on an HQD evaluation framework and K-means cluster analysis. Our results depict the characteristics of five types of secondary cities in six dimensions: urban size, social vitality, innovation capacity, industrial structure, regional embeddedness, and green transformation. By doing so, the paper fills the research gap of insufficient knowledge of mega-regional unevenness and the challenges faced by secondary cities moving towards HQD.

The results are significant for more targeted approaches to secondary cities towards HQD, especially regarding policy recommendations. On one hand, the typological study brings a new methodological perspective on policy formulation. Traditionally, policy formulation has often been based on territorial boundaries: a province or a mega-region as defined in spatial plans. We believe that formulating policies based on different types of cities sharing previously undetected similarities across various indicators allows both the cities and higher-level governments to share best practices and lessons and improves the effectiveness of the policies. The approach can, therefore, promote cooperation between cities of the same type and encourage complementary relations between different types of cities to alleviate the unevenness of HQD trajectories in mega-regional systems. In addition, summarizing the characteristics and challenges of secondary cities based on their HQD performance provides a foundation for formulating targeted policies and spatial planning adjustments. For example, for type A cities, emphasis should be placed on improving innovation capacity and transforming secondary industries to avoid over-reliance on a single economic sector. For type B cities, regional policies should coordinate their spatial relations with core cities to avoid demographic, industrial, and investment polarization and further loss of political voice due to their small size. For type C, mega-regions facing the challenge of common decline, the development paths of core and secondary cities should be considered in a coordinated way, rather than focusing only on the revival of the core city. For type D, the spatial and governance scope of the mega-region needs to be calibrated with the ability of the core city to support the surrounding secondary cities. For type E, the key policy question is how these cities can navigate under the shadow of the metropolis to avoid excessive polarization.

This study also contributes to global research of secondary cities. On one hand, we show that the concept of "secondary city" based on intercity relations also has the potential describe regional uneven development in China. This extends the policy implications of dealing with "secondarity": different spatial and governance contexts, core city types and dimensions of unevenness tend to generate analogous processes that lead cities into widely different trajectories, many of which implicate a 'metropolitan shadow' and weaker economic performance, fewer amenities and lower quality of life than expected in cities well connected to powerful cores (Meijers and Burger, 2022). This is in line with what we define here as the problems of polarization and peripheralization of Chinese secondary cities.

Therefore, determining the typology of Chinese secondary cities expands the possibilities for global academic and policy exchange and cooperation, and provides additional references for planning policy formulation for secondary cities. Methodologically, using cluster analysis based on relational aspects between core and secondary cities to create a typology is not commonly applied in the international literature and we expect that this approach can play a broader role in other contexts to enrich the understanding of secondary cities.

Finally, there are also some limitations of this paper. Although we trust the validity of this typology, secondary cities are unique due to their different cultural identity, resource endowments, regional environments, and related local policies. Moreover, the data presented in this paper only paints a broad picture of the different types of secondary cities, and the realistic challenges they face cannot be demonstrated. This is the limitation of our study. However, the paper provides a meaningful foundation and support for future research to respond to these limitations. More detailed empirical research and case studies are necessary, including more elaborate evaluations of the performance of different types of secondary cities based on specific development dimensions; investigations of HQD mechanisms, pathways, and effectiveness based on specific types of secondary cities; and studies of the implementation impacts and coping strategies of different types of secondary cities under specific policy perspectives.

CRediT authorship contribution statement

Yizhao Du: Conceptualization, Data curation, Funding acquisition, Methodology, Visualization, Writing – original draft. **Rodrigo V. Cardoso:** Conceptualization, Data curation, Methodology, Writing – review & editing, Supervision. **Roberto Rocco:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Fig. 1A

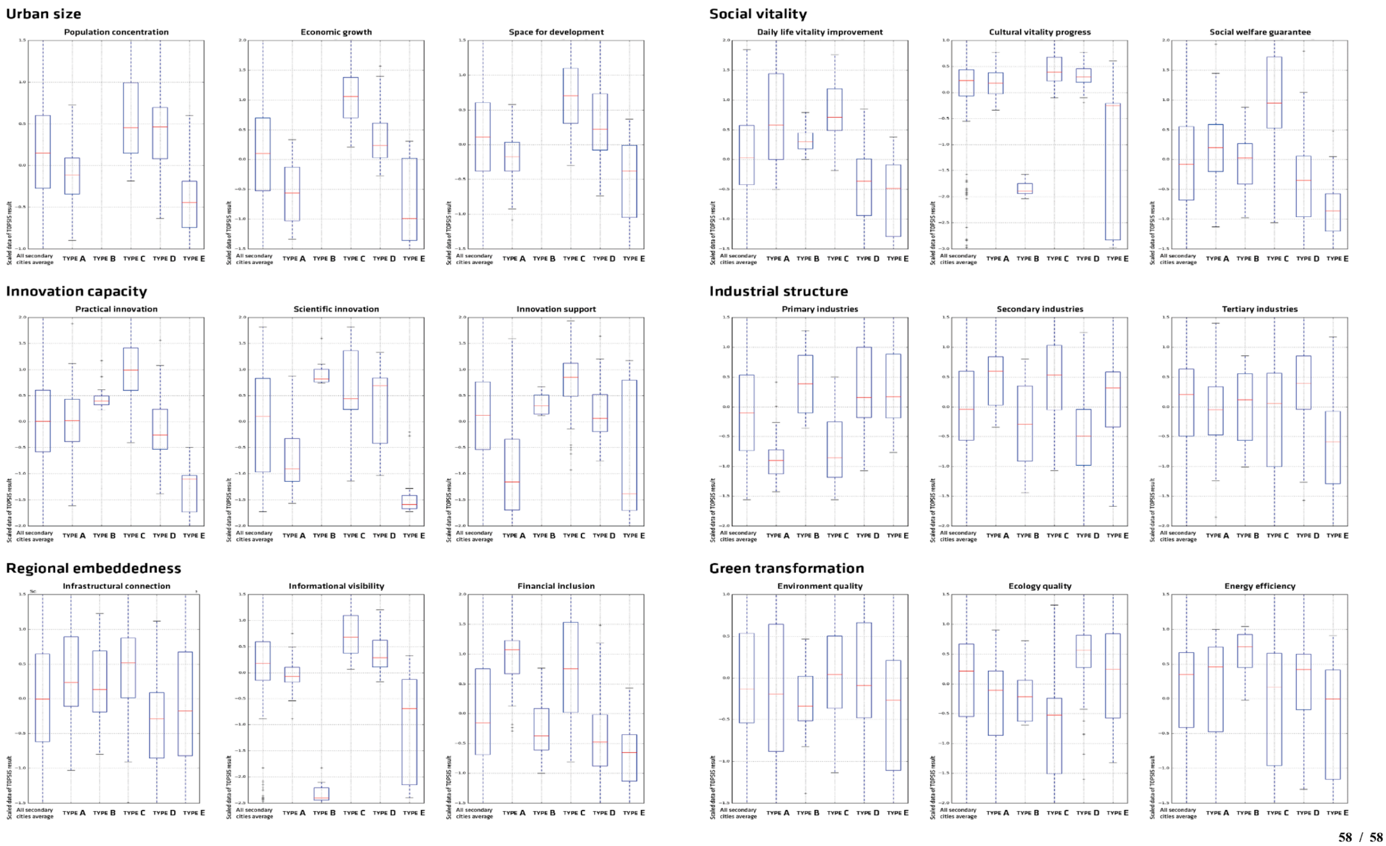

Fig. 1A. Boxplots analysis for comparing different types of secondary cities

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