Towards the analysis of urban livability in China: spatial–temporal changes, regional types, and influencing factors

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Abstract
The increasing drift of urbanization and its impact on urban human settlements are of major concern for China cities. Therefore, demystifying the spatial–temporal patterns, regional types, and affecting factors of urban livability in China is beneficial to urban planning and policy making regarding the construction of livable cities. In accordance with its connotation and denotation, this study develops a systematic evaluation and analysis framework for urban livability. Drawing on the panel data of 40 major cities in China from 2005 to 2019, an empirical research was further conducted. The results show that urban livability in China has exhibited a rising trend during the period, but this differs across dimensions. The levels of urban security and environmental health are lower than those of the three other dimensions. Spatially, cities with higher livability are mainly distributed in the first quadrant divided by the Hu Line and Bole-Taipei Line. Cities in the third quadrant are equipped with the lowest livability. In addition, the 40 major cities can be divided into five categories, and obvious differences exist in terms of the geographical distribution, overall livability level, and sub-dimensional characteristics of the different types. Furthermore, the results of the System GMM estimator indicate that the overall economic development exerts an inhibiting effect on the improvement of urban livability in present-day China, but this logical effect exhibits obvious heterogeneity in different time periods and diverse city scales. Finally, there are also differences in the influencing direction and degree of specific economic determinants.

Keywords Urban livability · Spatial–temporal analysis · Regional types · SYS-GMM method · Influencing factors · China

Introduction
Since humankind entered the age of industrial civilization, urban areas or city-regions, as the main gathering space for population and economic activities, have attracted more and more people to relocate there. The rapid advancement of industrialization and urbanization, on the one hand, grants opportunities for collective growth and development to urban areas for superior economic prosperity and community wellbeing (Monkkonen et al. 2018; Yassin 2019). On the other hand, however, the rising industrialization and urbanization rates and the resulting detrimental pressure on urban ecological environment, amenities, and associated quality of life of urban communities have become critical worldwide phenomena (Ellis and Roberts 2016; Fu and Zhang 2017; Kumar and Rai 2014). This coexistence of the twin yet contradictory scenarios is very common in the vast number of developing countries. Taking the world’s largest developing country, China, as an example, while the past few decades have witnessed great achievements in terms of both economy and urbanization, scholars have also observed increases in traffic congestion, air pollution, property prices, along with shrinking public services, and aging infrastructure in Chinese cities (Ouyang et al. 2017; Zhan et al. 2018; Xiao et al. 2022).

To this end, both researchers and policymakers are dedicated to searching for a reconciliation of the twin sides and seeking a complementary perspective of viewing development comprehensively. Accordingly, livability has gradually
become an increasingly important parameter for sustainable urban development, through which researchers can manage the totality of the twin sides of development (Kaal 2011; Kashef 2016). In addition, livability even emerges as a prime agenda for social wellbeing in city-regions throughout the world (Paul 2020). Therefore, to determine the shortcomings in the construction of livable cities, investigate the reasons thereof, as well as to explore the points that must be valued in the future have attracted widespread attention among the academic community and social circles (Fang et al. 2021a, b).

“Livability” is people’s eternal pursuit of ideal urban human settlements, and it is a multifaceted concept associated with many domains of the living environment in urban areas (Kashef 2016; Zhang 2016). The presently available research has provided a better understanding of the connotation, assessment, and spatial patterns of urban livability (Howard 1989; Ghasemi et al. 2018; Mahmoudi et al. 2015; Tolfo and Doucet 2021; Zhan et al. 2018). These studies, however, still exhibit several limitations. First, in terms of the evaluation dimensions and indicators of urban livability, many previous studies have overemphasized the role of economic factors (Chen and Cha 2010; Wang et al. 2017). Although there is currently no unified standard for the evaluation of livability, whether it should be included in the dimension of economic development is debatable. Despite the fact that economic development may exert a positive influence on urban livability (Tang et al. 2017), it may also lead to negative impacts (Mouratidis 2020; Sofeska 2017). Second, from the perspective of spatial analysis, there are also possibilities for attempting new schemas. Most existing studies regarding regional or urban differences in China are accustomed to following the analytical mindset of “national-east-central-west” (Li and Jin 2012; Li, et al. 2021a, b, c). However, few studies have explored the spatial pattern of urban livability based on the four quadrants divided by the Hu Huanyong Line and Bole-Taipei Line (Fang 2020; Fang et al. 2021a, b). This spatial thinking provides a new perspective by which to seek the heterogeneity with the traditional classification from the “East, Central, and West.” Finally, concerning the analysis of factors affecting livability, most studies have mainly depicted or revealed the degree of relevance or coordination between urban livability and other factors by applying correlation analysis, coupling models, and so forth (Yu and Wang 2014). However, the internal mechanism and transmission pathways of their influence have yet to be explored, particularly the influence of economic factors. Under the background that economy and urbanization of China are gradually entering the stage of high-quality development, clarifying the influence of economic development on urban livability is of significant academic and practical value.

To fill in these research gaps, this paper draws on the existing theory and practice of thought in the field of urban human settlements, and takes China as an example to propose a data-driven analysis and country-wide level assessment system of urban livability. The research framework of this paper is shown in Fig. 1. Specially, this paper aims to answer the following questions: How can a comprehensive and scientific evaluation index system of urban livability be established? How can the spatial pattern of urban livability be demystified, and how can the regional types be divided? What economic factors are obviously affecting or restricting the urban livability? What measures can be adopted to boost urban livability based on the research findings? Empirically, the solution of these questions can enrich the literature about urban livability, and also offers important references to policymakers for deploying more effective livable city construction projects in the future.

The remainder of this paper is organized as follows. “Literature review” offers a brief literature review about urban livability. “Materials and methods” presents the
methodology used in the study, including the study area, evaluation index system, data collection, and model specification. The empirical results are discussed in “Results and analysis”. “Conclusions and policy implications” concludes the paper by providing the key findings of the study and policy recommendations.

**Literature review**

This study is built at the interlock of several branches of literature, but mainly three branches are involved: the first is the connotation and definition of urban livability; the second is the measurement approaches of urban livability; and the last is dimensions or factors affecting urban livability.

**The definition and connotation of urban livability**

Urban livability is part of the research category of human settlements (Doxiadis 1968). Although often used liberally, the term urban livability lacks a consensus of what exactly it refers to, due to its complex and multi-dimensional nature. Overall, the connotation or definition of livability discussed in existing literature varies depending on the priority of different concerns. Some scholars have pointed out that urban livability is a relatively objective concept. For example, Newman (1999) claimed that urban livability refers to the human requirement for social amenity, health and wellbeing, and includes both individual and community wellbeing. Other scholars interpret livability from a relatively subjective perspective. For instance, Zhan et al. (2018) held that urban livability is the urban quality of life and individual wellbeing related to the local urban environment. In addition, livability has been considered a synthetic concept. For example, McCann (2007) held that livability is the integration of the objective urban environment and human subjective feelings. Zhang (2016) argued that livability should be the organic combination of a pleasant natural ecological environment and a harmonious social and cultural environment. In general, the above-mentioned understandings have indicated that livability is a broad term encompassing a number of urban environment characteristics which affect the attractiveness of a given place. Moreover, urban livability has sometimes been considered the quality of life experienced by residents of a city (Lauster 2019; Papachristou and Rosas-Casals 2019) and the standard of living or general wellbeing of the population in an area (Mouratidis 2020; Okulicz-Kozaryn 2011). It can be seen that there is still no unified definition of urban livability, and the concept of livability will continue to expand and deepen with further urbanization and socioeconomic development.

**The evaluation of urban livability**

Consistent with the diversified conceptualizations of urban livability, no consensus has been reached regarding the measurement methods of urban livability (Paul and Sen 2018; Badland et al. 2014; Xiao et al. 2022). In general, there are three approaches which have been adopted for the evaluation of urban livability. The first one is the comprehensive evaluation method, which measures urban livability through specific measurement dimensions and objective indicators (Wang et al. 2020), and the common technical means of which is constructing corresponding evaluation index system (Zhang et al. 2021). Some studies pointed out that livable city is the result of residents’ satisfaction with urban construction, including environmental quality, urban safety, medical care, transportation, and other aspects (Kostas Mouratidis and Yiannakou 2022; Li et al. 2020). Accordingly, the second method for evaluating livability is the subjective evaluation based on residents’ perception. Questionnaire surveys, telephone interviews, direct interview, and structural equation models are often adopted when applying this paradigm (Zhan et al. 2018; Stanislav and Chin 2019; Paul 2020). The third method is the geographic information system (GIS) method; for instance, tapping into the power of GIS and remote sensing technologies to generate a set of urban livability evaluating indicators via extracted land use information (Fu et al. 2019).

In addition, some researchers tried to combine subjective and objective indicators to comprehensively assess urban livability, among them, urban environmental quality and urban safety are the core indicators of the objective index system, and residents’ happiness is the symbolic indicator of the subjective index system (Mouratidis 2019; Tan et al. 2020; Goerlich and Reig 2021). Recently, methods such as agent-based modeling (ABM) and fuzzy inference systems have also been gradually introduced into urban livability evaluation (Cao et al. 2021; Karasan et al. 2019). Overall, urban livability can be assessed with objective and subjective indicators and at different spatial scales, each of the evaluation approaches mentioned above possesses their own specific advantages, and they are all applicable in different ways.

**The dimensions or determinants of urban livability**

On the basis of selecting the measurement method, it is critical to determine reasonable evaluation dimensions and indicators. Urban livability is a multi-dimensional concept possessing rich connotations, and it is instructive to evaluate it from multiple dimensions and multidisciplinary angles (Mouratidis and Yiannakou 2022; Pacione 1990; Ruth and Franklin 2014; Tang et al. 2017). For example, Lauster (2019) believed the term of livability is meant as a shorthand for resident quality-of-life, itself influenced by...
policies that govern ownership and tenure, services and amenities, affordability, habitability, accessibility, location, and cultural adequacy of living conditions. Conceptually, the determining factors or variables affecting urban livability can be summarized in terms of urban security (Tao et al. 2014; Zhan et al. 2018), environmental health (Buys & Miller 2012; Rehdanz and Maddison 2008; Tan et al. 2020), convenience of residents’ daily life (Mohit et al. 2010; Cao et al. 2021), natural environment (De Vos et al. 2016; Zhang et al. 2021), economic prosperity (Zanella et al. 2014; Tao et al. 2017; Xiao et al. 2022), sociocultural environment amenities (Li and Wu 2013; Zhang 2016), and other aspects. These elements are crucial supports for the construction of livable cities, and they are also widely applied in livability evaluation.

Sometimes, scholars do not directly analyze the influencing factors of urban livability, but explored determinants of subjective satisfaction or wellbeing (i.e., living or life satisfaction, happiness, or some other self-reported measure of quality of life) in cities and neighborhoods (Goerlich and Reig 2021; Mouratidis 2019; Papachristou and Rosas-Casals 2019). Recently, the relationship between tourism development (Liu et al. 2017), climate change (Liang et al. 2020), and CEO compensation (Li et al. 2021a, b, c), and urban livability has also attracted the interest of scholars. Furthermore, many researchers have argued that residents’ individual socioeconomic attributes such as age, income, education, and gender can also affect the assessment of urban livability (Chen et al. 2013; Ren and Folmer 2016). The influencing direction and degree of each attribute are also founded to be different under diverse contexts (Mouratidis and Yiannakou 2022; Zhan et al. 2018). Moreover, on the basis of understanding the determinants of urban livability, a large number of studies have been exploring how to make cities more livable (Tonne et al. 2021). Accordingly, the core framework and planning strategies of livable city construction, as well as city health examination methodology have been proposed and applied (Shekhar et al. 2019; Wey and Huang 2018; Zhang et al. 2016, 2021).

Materials and methods

The construction of index system

In the present study, urban livability is considered to be the complete unity between pleasant natural ecological environment and harmonious sociocultural environment, which is similar to the definition proposed by Zhang (2016). According to the research purpose and data availability, a comprehensive evaluation method was selected and applied to measure urban livability in this study. Compared with subjective evaluation or questionnaire methods, this method is more objective and accessible to perform time series analysis regarding spatial patterns and influencing mechanisms (Liang et al. 2020). In addition, although GIS analysis and related big data technology exhibit good immediacy, they may be slightly insufficient in explaining the impact mechanism of urban livability, due to the lack of abundant sample attribute information (Liu 2016).

The establishment of indicator system is the basis for the comprehensive evaluation method. We build the indicator system based on two related efforts. The first one is some official standards for urban livability or urban human settlements, such as the Scientific Evaluation Criteria Livable City issued by Ministry of Housing and Urban–Rural Development of China (2008), the criteria used by the China Human Settlements Award (Ma et al. 2014), and the Rockefeller Foundation’s Index System for human settlements in resilient cities (Rockefeller Foundation 2014). The second one is meta-analysis on the existing body of relevant literature. Existing literature have suggested diversified urban livability assessment systems suitable for different scales and urban conditions. However, no consensus has yet been reached. Through extensive review and research on urban livability indicators used in relevant literature, it appears that for the first-level indicators, most scholars (Paul and Sen 2018; Ghasemi et al. 2018; Tang et al. 2017; Xiao et al. 2022; Zhang 2016, etc.) and research institutes (including the Economist Intelligence Unit, Chinese Academy of Urban Sciences, Institute of Geographic Sciences and Natural Resources Research, etc.) highlighted the following aspects, namely natural environment, urban security, environmental health, sociocultural environment, and convenience of public facilities.

In addition, some researchers have stressed that economic prosperity is an important guarantee for residents’ material life and a crucial basic condition for livable city construction, thus economic factors should be included in the livability evaluation system (Sofeska 2017; Zanella et al. 2014; Xiao et al. 2022). However, the evaluation system of the present study overlooked the economic benefits and other conceivable economic pressure, due to the fact that economically developed cities also tend to concurrently undergo enormous pressure such as high costs of housing and living, which in turn pose challenges to urban livability (Ogneva-Himmelberger et al. 2013; Zhan et al. 2018).

On the basis of aforementioned official criteria and literature syntheses, and considering both the availability and quality of research data, the operability of programming, and five experts’ opinions in the field, a five-dimensional index system with 29 respective indicators was established to fully describe the livability of urban areas (Table 1). Next, we
will elaborate on each dimension and its specific indicators choices in detail.

The first dimension is urban security, which is often considered as a prerequisite in shaping livable urban environments (Tao et al. 2014; Zhan et al. 2018), due to the fact that it is directly related to whether the lives and property of city dwellers can be guaranteed. It is also the most basic need of contemporary residents (Buys and Miller 2012). There are five indicators in the subsystem of urban security. Urban security is significantly affected by factors such as crime rate and unemployment rate (Zhan et al. 2018), but the data of urban crime rate is not available. Some studies believed that crime rate has a significant positive relationship with the poverty level of urban residents (Martínez et al. 2015). Therefore, unemployment rate and Engel coefficient were used in the evaluation of urban safety. Additionally, fire incidence rate and number of deaths in traffic accidents are also intuitive reflections of whether a city is safe or not (Maria et al. 2010). Moreover, emergency shelters can provide important guarantee and support for residents to cope with natural disasters such as floods, earthquakes, and other public safety emergencies, and it has been applied in some urban assessment cases (Yu and Wen 2016; Cao et al. 2021).

The convenience of residents’ daily life is also an important aspect which characterizes the livable quality of a city (Mohit et al. 2010). This dimension focuses closely on the convenience of urban public services, which reflects city dwellers’ perceived access and quality of public facilities, such as facilities for shopping, education, healthcare, culture, entertainment, and so on (Zhan et al. 2018; Zhang et al. 2021). In general, the number or temporal accessibility of various public facilities is the common evaluation indicators (Li et al. 2021a, b, c). There are six indicators adopted in this paper. Specially, practical urban road area and number of public transportation bus were selected to represent the level of urban transport development. Number of hospital beds and number of doctors were used to reveal the urban ability of responding to public health crisis. Number of teachers in primary and secondary schools and number of public library books were adopted to reflect the level of educational services and construction.

The third dimension is sociocultural environment amenity. Although it is not a physical environment factor, it is also a crucial component of the urban living environment. Harmony and livability account for the highest requirement of urban development, which is also related to the happiness of residents (Sirgy and Cornwell 2002). This dimension of pleasing urban sociocultural environment mainly includes a set of indicators, such as high-quality citizens, instant messaging conditions, good openness and social inclusion, and benign cultural atmosphere (Li and Wu 2013; Zhang 2016). Based on China’s national conditions and the principle of practical operability, six secondary indicators such as the communication index, visitor size/urban population, proportion of population with college degree and above, number of colleges and universities, number of theaters and cinemas, percentage share of employment in entertainment, culture, and accommodation were adopted to the evaluation of social comfort indicators.

The fourth dimension is environmental health, which is a crucial condition for the construction of livable cities. Urban residents from all walks of life have the right and hope for health (Buys and Miller 2012; Rehdanz and Maddison 2008). In particular, environmental health mainly emphasizes environmental pollution with respect to water, solid waste, ambient air, and noise in urban areas (Badland et al. 2014; Węziak-Białowolska 2016). The environmental health subsystem contains six indicators in this paper. Amount of SO2 per unit of urban area (a negative indicator), percentage of area meeting national standard of environmental noise, and percentage of industrial sewage discharged meeting national standard were used to characterize the quality of urban atmosphere, noise, and water environment. Comprehensive utilization rate of industrial solid waste was selected to represent the urban ability to recycle industrial waste products. Harmless treatment rate of domestic garbage and concentrated treatment rate of domestic sewage were chosen to reveal the supporting degree of urban rubbish and sewage centralized collection and disposal facilities.

The last dimension is natural environment. With the development of the social economy, urban residents are increasingly desirous of a delightful natural environment (Rehdanz & Maddison 2008; Zhang et al. 2021). Favorable climate, good green urban environment, access to parks and water areas, and suitable open spaces have been playing increasingly important roles affecting urban human settlements (De Vos et al. 2016; Wang et al. 2020). All of these elements form an essential material basis for constructing livable cities. The average temperature and relative humidity in July and the average temperature and sunshine hours in January were selected as the climate factors; considering that the temperature and humidity in July are not as high as possible, the difference between them and the most suitable values for the human body was calculated (Zheng 2014). Although existing studies have emphasized the influence of topography, coast, etc. on urban livability (Wang et al. 2017), the specific relationship between these elements and livability is still unclear, and different residents may have different preferences for them. Therefore, we did not consider factors such as topography and landforms, and only select area of parks’ green land per capita and percentage of green covered area in the built-up area to reflect the urban greening degree and landscape.
The weight calculation of each indicator

As for the indicator weight setting, a combination of objective and subjective weighting method was applied. This method can effectively overcome the shortcomings of using a single means to determine the weight, and make the evaluation results more scientific (Wang et al. 2017). This process consists of three steps.

First, the criteria importance through inter-criteria correlation (CRITIC) method was used to calculate the
objective weight, which was proposed by Diakoulaki et al. (1995). Its principle is to use the contrast intensity of indicators and confliction between indicators to reflect the amounts of both information and independence of the indicator, thereby determining the weight. For this reason, it has significant advantages over other weighting methods which only consider the indicator information or independence. Specially, we need to calculate $M_j$, which refers to the amount of information contained in the indicator $j$. The formula is as follows:

$$M_j = c_j \sum_{i=1}^{n} (1 - r_{ij})$$  \hspace{1cm} (1)

where $c_j$ is the variation coefficient of the indicator; $m$ and $n$ are the number of index factors, and $r_{ij}$ is the correlation coefficient between indicators $i$ and $j$. Their formula is as follows:

$$c_j = \sigma_j / \overline{x}_j$$  \hspace{1cm} (2)

$$\overline{x}_j = \frac{1}{m} \sum_{i=1}^{m} x_{ij}$$  \hspace{1cm} (3)

$$\sigma_j = \frac{1}{n} \sum_{i=1}^{n} (x_{ij} - x_j)^2$$  \hspace{1cm} (4)

$$r_{ij} = \sum_{i=1}^{m} (x_{i} - \overline{x}_i)(x_{j} - \overline{x}_j) / \sqrt{\sum_{i=1}^{m} (x_{i} - \overline{x}_i)^2 \times \sum_{j=1}^{m} (x_{j} - \overline{x}_j)^2}$$  \hspace{1cm} (5)

In general, the greater the $M_j$ is, the more information would be contained in indicator $j$, and the greater the weight would be. Next, the $M_j$ was normalized, and the objective weight $(\omega_{ij})$ of indicator $i$ can be obtained:

$$\omega_{ij} = M_j / \sum_{j=1}^{n} M_j$$  \hspace{1cm} (6)

Second, by consulting experts in the field of urban geography and human settlements, the opinions of experts were recorded, processed, analyzed, and inducted. The expert scoring method and analytic hierarchy process (Saaty 1977) were adopted to determine the subjective weight of each indicator, namely $\omega_{2j}$. Since this method is very mature in application, the specific process will not be described in detail here.

Finally, the combined weight expressed by $\omega_j$ can be determined based on the objective weight $\omega_{ij}$ and subjective weight $\omega_{2j}$. Clearly, $\omega_j$, $\omega_{1j}$, and $\omega_{2j}$ should be as close as possible. Accordingly, the function was constructed according to the principle of minimum relative entropy:

$$F = \sum_{i=1}^{m} \omega_i (\ln \omega_i - \ln \omega_{2i}) + \sum_{i=1}^{m} \omega_{ij} (\ln \omega_{ij} - \ln \omega_{2j}), \sum_{i=1}^{n} \omega_i = 1, \omega_i > 0.$$  \hspace{1cm} (7)

With regard to this function, the Lagrange multiplier method was used to obtain the optimal solution (formula 8), i.e., the weight of each indicator. For the specific derivation process, please refer to Appendix. The final weight of each indicator is shown in Table 1.

$$\omega_j = \sqrt{\omega_{ij} \times \omega_{2j}} / \sum_{j=1}^{n} \sqrt{\omega_{ij} \times \omega_{2j}}$$  \hspace{1cm} (8)

Combined with the standardized value ($x_{ij}'$) and weight of each evaluation indicator $(\omega_j)$, the comprehensive livability score $(Z_i)$ of major cities in China was calculated through the linear weighting method (formula 9). The higher the score is, the more livable the city will be.

$$Z_i = \sum_{j=1}^{m} x_{ij}' \times \omega_j$$  \hspace{1cm} (9)

### Cluster analysis

Cluster analysis is a useful statistical tool for classifying objects of study and was applied to conduct type identification in this study. Specially, the 40 cities in China were taken as the basic units, and the research units were divided by using the Furthest Neighbor (Complete Linkage) method. The results obtained by this method are more detailed, comprehensive, and reasonable than traditional qualitative classification methods. Compared with K-means clustering, the cluster pedigree map of this method can more clearly express its numerical classification results, especially when the number of samples is small (Niknam and Amiri 2010). There were three steps for this method:

First, the Cosine distance (namely cos($x$, $y$)) is selected to define the distance between the samples, and the calculation formula used is as follows:

$$\text{cos}(x, y) = \frac{\sum_{i=1}^{n} (x_i - y_i)^2}{\sqrt{\sum x_i^2} \times \sqrt{\sum y_i^2}}$$  \hspace{1cm} (10)

Next, a distance matrix between samples can be obtained based on the distance coefficient cos($x$, $y$) between any two sample points.

Finally, the longest distance method was adopted for clustering. If $x_i$ is any sample in the class $G_p$ and $y_j$ is any sample in the class $G_q$, then the longest distance in the class $G_p$ and $G_q$ is:

$$D_{pq} = x_i \in G_p \text{max} \quad y_j \in G_q \text{cos}(x, y)$$  \hspace{1cm} (11)

where the smaller cos($x$, $y$) is, the smaller the distance between samples will be. The closer the properties of sample
x and sample y are, then the more they can be divided into the same type (Hu and Wang 2020).

### Identification strategy

Although the dimension of economic development was not included in the assessment of urban livability, this does not signify that we have completely ignored this factor. In this section, in order to analyze and discuss whether economic development can bring more urban livability, we construct the following econometric model.

\[
\ln U_{it} = \alpha_0 + \alpha_1 \ln U_{i,t-1} + \alpha_2 \ln EG_{it} + CV_{it} + \epsilon_{it} \tag{12}
\]

where \( U_{it} \) represents the urban livability of city \( i \) in period \( t \); \( EG_{it} \) is the core explanatory variable, which refers to the level of economic development of city \( i \) in period \( t \), and the per capita labor productivity to was adopted to represent urban economic development; \( CV_{it} \) is a set of control variables at the firm level, including credit scale, level of science and technology, industrial structure, financial sufficiency, economic openness and square of GDP per capita; and \( \epsilon_{it} \) is the random disturbance term of the model. In addition, considering the possible lagging impact of economic development and other factors on urban livability, the data from the previous period \((t-1)\) of urban livability are introduced to better eliminate the impact of endogeneity on the empirical results.

As for the specific estimation method, the system generalized method of moments (SYS-GMM) estimator was used to estimate the model (Arellano and Bover, 1995). It can exclude the dynamic panel bias generated from traditional measurement methods such as OLS estimator (Blundell and Bond 1998). Additionally, by combining the horizontal regression equation and the difference equation for estimation, the SYS-GMM estimator can effectively overcome the issues of fixed effects and endogeneity of regressors (Biresselioglu et al. 2016).

### Research area and data sources

For the empirical analysis, in this paper, 40 major cities in China were selected, including 4 municipalities, 27 provincial capitals, and 9 recognized livable prefecture-level cities (Fig. 2). In 2020, these 40 cities accounted for 20.43% of the total population of China and contributed 41.65% of the national GDP, yet accounted for only 5.75% of the total land of China (National Bureau of Statistics of China 2021). There are two main reasons for choosing these cities: First, the primary data of these cities are relatively complete and readily available. At the beginning, we planned to conduct research with more than 300 prefecture-level cities as samples. However, when collecting data according to the established indicator system, we found that the data for some indicators of most cities were incomplete and inaccessible. That is why we did not choose about 300 prefecture-level cities. More importantly, these 40 cities are the most representative cities in different regions of China, representing the highest level of China’s economic and social development, and are also frequently selected as case sites for empirical research on livability (Tang et al. 2017; Zhang et al. 2016). In addition, this study also aims to explore the relationship between urban livability and economic development. Therefore, in addition to the municipalities and provincial capitals, 9 recognized livable prefecture-level cities were selected.

The raw data corresponding to each indicator are mainly derived from the China City Statistical Yearbook, China Statistical Yearbook, China Meteorological Yearbook, China Tourism Statistical Yearbook, and the statistical yearbooks of various cities from 2006 to 2020. Additionally, the China Economic Database, 1 and China Meteorological Science Data Sharing Service Platform 2 also contributed to the data collection. Significantly, the data collection is based on the whole city area. In addition, we performed a winsorizing process on extreme values, and a small amount of missing data is also supplemented by the interpolation method.

### Results and analysis

#### Spatial–temporal changes in urban livability

#### Temporal changes in the total and sub-dimension of urban livability

Under the above-mentioned framework and methods, the evaluation results are obtained, as detailed in Fig. 3. It is shown that the livability of large and medium-sized cities in China has generally presented a rising trend from 2005 to 2019. The average value of the comprehensive livability index increased from 0.2684 to 0.3202 in the same period, for an increase of 19.31%. This is mainly due to the fact that, since the beginning of the twenty-first century, China has continually promoted the transformation of urban development goals from quantity to quality, which has led to the continuous upgrading of urban ecological livable quality. However, it is also noteworthy that the present level of urban

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1 The website is: https://info.ceicdata.com/ceic-database-demo-requesst-social-media-cn.

2 The website is: http://cdc.cma.gov.cn.
livability in China is not very high, and there remains much progress to be made in regard to the livable cities which people are satisfied with.

From the perspective of the compositional dimensions of livability, urban security has been at the end of the five sub-dimensions for a long period of time, and there has been no significant improvement in the past 15 years. The first reason for this may be that car ownership of urban residents has soared for the past several years, and the resulting traffic accident rate has continued to rise. Moreover, with changes in the international and domestic environment in recent years, various contradictions and risks have been deeply intertwined and rapidly penetrated. Accordingly, the new challenges caused by these issues have offset the progress made in other aspects of urban safety construction to some extent. Similarly, the dimension of environmental health has
been growing slowly for a long time, rising from 0.0442 to 0.0507, with an average annual growth rate of only 0.99%. Relatively speaking, the livability in the dimensions in terms of natural environment, sociocultural environment and convenience of public services has increased rapidly, with average annual growth rates all exceeding 1.6%.

**Spatial distribution characteristics of the urban livability**

By applying ArcGIS 10.3 software, the livability index of each city was spatially linked with the research units in vector format, and the spatial distribution map of comprehensive index of urban livability in China was drawn (Fig. 4). Here, the “Bole-Taipei Line” was introduced on the map, which was a significant new discovery made in China’s regional development research (Fang 2020). The Bole-Taipei Line and Hu Huanyong Line (the latter hereinafter referred to as the Hu Line) divide China into four quadrants, which provides a novel perspective for the study of regional spatial differentiation there. The four regions of the east, south, west, and north, respectively, correspond to the first, second, third, and fourth quadrants. Due to space limitations, only four representative time nodes are shown here (namely 2005, 2009, 2014 and 2019). It can be seen that, in addition to the decline in livability of a small number cities in 2014, the livability of Chinese cities is, overall, on the rise. This further verified the accuracy of the above-mentioned results of temporal changes in livability.

However, there are also some obvious spatial differences in urban livability in China. On one hand, along the Hu Line, there is a spatial pattern of east–west differentiation. Cities in southeastern China tend to have higher livability than those in the northwest. This may be due to the fact that the Hu Line is an important natural geographical, ecological, and environmental boundary, as well as a meteorological and climatic boundary in China (Chen et al. 2019). The environmental background established therefrom exhibits significant differences between southeast and northwest, which ultimately leads to a polarization trend in regional livability. In addition, the Hu line is also an important dividing line for population density in China. Therefore, it can also be seen from Fig. 4 that there strong spatial consistency exists between the livability of Chinese cities and its population distribution. On the other hand, there is little difference in urban livability between the two sides of the Bole-Taipei Line. In general, the livability of cities in northeastern China is slightly higher than that in southwestern China. However, along the Bole-Taipei Line from the southeast to northwest, the urban livability has been declining. This is mainly due to the fact that the Bole-Taipei Line is a gradual line both of China’s natural and anthropological geography (Fang 2020).

Based on the comparison of the four quadrants composed by the two lines mentioned above, cities with higher livability are mainly distributed in the first quadrant, i.e., the eastern coastal area. In 2019, its average livability index was 0.3585, which is much higher than the other quadrants. In addition, six of the 10 top cities are distributed in the first quadrant. The urban livability in the second quadrant is also relatively high, with an average value of 0.3367, which is second only to the first quadrant. Aside from a small number of cities such as Guiyang and Nanning, the livability index of more than 60% cities exceeds 0.26. In addition, urban livability within the first and second quadrants is also significantly different, namely coastal cities tend to be equipped with better livability than inland cities. Urban livability within the third and fourth quadrants is relatively balanced. However, their livability levels are generally lower, particularly in the third quadrant, the average livability index of which is only 0.2693. These regions lowered the overall urban livability in China, and urgently need to be improved.

**Type division of the urban livability**

In order to further observe the regional distribution characteristics of urban livability in China, the cluster method is applied to obtain the cluster pedigree map of urban livability, as shown in Fig. 5. Next, the 40 major cities in China were divided into five types. ArcGIS 10.3 was used to visualize the classification results (Fig. 6).

Cluster 1 contains Beijing, Shanghai, Guangzhou, and Nanjing, which are basically the most international metropolises with the most developed economies in China. In terms of spatial distribution, cluster 1 is mainly distributed in the first quadrant, and equipped with favorable climatic, hydrological, and topographical conditions. As for the urban livability index, this cluster has the highest overall score, with an average of 0.4183. Although these areas exhibit high population density and exert greater pressure on resources and the environment, they also focus more on the construction and development of human settlements than other areas. For instance, Beijing proposed the goal of building a livable city in its urban master plan as early as in 2005. The quality of urban human settlements there have also benefited from these related plans and initiatives. As depicted in Fig. 7, in addition to urban safety, cluster 1 fares well in all other four sub-dimensions. In particular, in the dimension of sociocultural environment amenity, it possesses absolute advantages due to its rich cultural, educational, scientific, and tourism resources. However, it should also be noted that some recession indicators or pressures are not shown in the evaluation indicator system, and they will also have an adverse impact on the livability of these cities, such as escalating and expensive housing prices. It has been found that many young white-collar workers residing there even exhibit an ideological trend of “fleeing Beijing, Shanghai, and Guangzhou” (Xiao 2016).
Hangzhou, Shenzhen, Suzhou, Xiamen, Ningbo, Qingdao, Wuhan, Chengdu, and Tianjin are laid in cluster 2. Spatially, cities in this cluster are distributed in the first and second quadrants, and all but Wuhan and Chengdu are coastal cities. However, these latter two cities are also situated along the Yangtze River. With regard to urban livability score, the average comprehensive index of this cluster is as high as 0.3538, second only to cluster 1, and some dimensions even exceed those in cluster 1. Compared with cluster 1, the weaknesses in this cluster may lie in high-end cultural and educational resources, the advancement of the industrial structure, and so forth. In recent years, building a modern city suitable for habitation, employment, and travel has become the development goal of many cities in cluster 2. Accordingly, if done properly, these cities also possess great potential in developing to become the most livable cities in China.

Cluster 3 includes Changsha, Kunming, Jinan, Dalian, Fuzhou, Zhuhai, Weihai, Chongqing, Hefei, and Shenyang. These cities are also mainly located in the first or second quadrants, and their comprehensive urban livability index is between 0.1382 and 0.3617. Generally, the quality of urban human settlements in this cluster is at a medium level with an average of 0.3215, which is slightly higher than the national average. However, compared with the first two regional types, the development of each dimension in cluster 3 possesses no competitive advantage. Although some cities have superior geographical conditions and human settlement backgrounds, these are not efficiently utilized or have already been exhausted, thereby resulting in air, water, and

![Fig. 4 The spatial distribution of livability of major cities in China](image-url)
soil pollution (Tang et al. 2017). These practical issues and a lack of prominent dimensions further limit the development of urban livability there.

Cluster 4 includes Haikou, Zhengzhou, Guiyang, Nan-chang, Changchun, Shijiazhuang, Hohhot, Taiyuan, Yin-chuan, and Lanzhou. In terms of spatial distribution, the cities in this cluster are scattered throughout the four quadrants, yet most of them are still concentrated in the first and second quadrants. In addition, all but Haikou are located in the interior of China. For a long period of time, the economic strength of some cities in this cluster has remained relatively limited. Under the same conditions, more resource elements will be invested in economic construction. Accordingly, there remains insufficient support for the construction of urban human settlements, and even the resource allocation will eventually be crowded out. For these reasons, the scores of each dimension in cluster 4 are lower than those of the first three clusters. Furthermore, for the sake of improving economic conditions and vitalizing economic activities, some rapid urban economic development and short-sighted urbanization strategies have led to resource and environmental problems. For example, haze and acid rain have become major environmental challenges for some of the cities mentioned above (Zhou et al. 2019).

Lhasa, Xining, Nanning, Urumchi, Harbin, and Sanya fall within cluster 5. This cluster has the lowest livability score among the five. Although this cluster’s urban livability has been improved over time, the average livability index has been lower than 0.2 for many years. As for individual sub-dimensions, the sequence of the scores of each dimension is similar to that of cluster 4, yet the scores are all lower than those of cluster 4. The first possible reason for this is that the limitations of natural conditions render the ecological environment fragile. Although Sanya and Harbin are situated in eastern China, they are respectively located at the southernmost and northernmost points. Few people have been willing to settle in these cities for a long time due to the relatively extreme climates there. Moreover, the remaining four cities are mostly concentrated in the third quadrant, namely the inland areas of western China with long distances from developed coastal areas. The natural environment background in these areas is highly restrictive and constrained. In addition, the outdated economy also has limited support for the construction of urban human settlements. All of these reasons have impeded and reduced the score of urban livability.

Analysis of influencing factors of urban livability

The level of urban livability is affected by many factors. In fact, the selection of the dimensions of livability evaluation is also based on their influence on livability or their correlation with livability. Therefore, in this section we only attempt to test the crucial economic determinants influencing urban livability of 40 Chinese cities in the period of 2005–2019.

Descriptive statistics and validity tests

Table 2 illustrates the average, minimum, maximum, and standard error of the series. Additionally, some dispersion statistics of the samples, such as variance inflation factor (VIF) and value of Fisher-PP are also presented in Table 2. On one hand, multicollinearity illustrates a high degree of correlation among the regressors which arises when a large number of regressors are included in the model. Evidently, all regressors in the model are free of collinearity, as the variance inflation factor is less than 10 (Kennedy 1992). On the other hand, the time series of many macroeconomic variables are non-stationary, which can easily lead to spurious regressions. In order to make the non-stationary series stable, in this paper, the logarithm or difference process...
was used on some variables. Moreover, the Fisher-PP method is also utilized to perform unit root tests on all of the panel data, and the results are shown in the final column of Table 2. These observations indicated that the variables after being preprocessed are stable, which can avoid false regression and ensure the validity of the regression results.

As for the System GMM estimator, although a two-step estimator is more effective than a one-step estimator, many studies have confirmed that the efficiency gain is minor, and that the asymptotic standard errors concerning two-step GMM estimators in finite samples can be extremely biased in the downward direction (Biresselioglu et al. 2016; Hoeffler 2002). In this respect, in Table 3, only one-step System GMM estimates are reported. In addition, the regression results give the AR(2) test and Sargan test statistics, allowing us to detect the validity of the instruments used in the GMM regressions. As depicted in the final two rows...
of Table 3, the results of the Sargan test indicate that there is no over-identification of instrumental variables in all estimation results. In addition, the AR(2) test results are not rejected at the 10% significance level, thereby suggesting the validity of all the instrument variables selected in this model, with no second-order sequence correlation of the random error term (Blundell and Bond 1998; Wu et al. 2020). Finally, the Ward test results also indicate that the overall model is highly significant.

Impact analysis of the explanatory variables on urban livability

According to the SYS-GMM regression results of the entire sample base, in addition to the impact of its own past stock and other factors, economic development exerts a significantly positive effect on the improvement of urban livability, such that a 1% increase in per capita labor productivity leads to the promotion of urban livability of about 0.019%. However, the coefficient changes from positive to negative.

### Table 2: Descriptive statistics

| Variable | Definition                      | Observation | Mean   | Std. dev | Minimum | Maximum | VIF | Fisher-PP |
|----------|---------------------------------|-------------|--------|----------|---------|---------|-----|-----------|
| LnUL     | Logarithm of urban livability   | 600         | −1.430 | 0.324    | −2.241  | −0.353  | 100.06*** | (0.00)    |
| LnEG     | Logarithm of economic development | 600         | 17.887 | 1.114    | 14.164  | 20.232  | 3.16  | 244.05*** | (0.01)    |
| CS       | Credit scale                    | 600         | 4.110  | 3.505    | 0.153   | 17.176  | 1.91  | 402.22*** | (0.00)    |
| SI       | Level of science and technology | 600         | 3.456  | 0.435    | 2.408   | 4.399   | 1.54  | 522.32*** | (0.00)    |
| DF       | Difference of fiscal adequacy   | 600         | −22.917| 94.565   | −647.209| 232.062 | 2.13  | 681.84*** | (0.00)    |
| D LnSU  | Difference of industrial structure coefficient logarithm | 600 | 0.037 | 0.109 | −0.341 | 0.429 | 2.59 | 510.32*** | (0.00)    |
| LnAG     | Logarithm of (GDP per capita)² | 600         | 22.459 | 0.975    | 19.913  | 24.299  | 1.77  | 229.07*** | (0.00)    |
| LnOP     | Logarithm of economic openness  | 600         | −3.606 | 1.051    | −10.407 | −1.678  | 1.42  | 108.24*** | (0.00)    |

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the z-values of the coefficients.

### Table 3: The estimation results of System GMM

| Variables                  | Entire sample | Entire sample | Before entering the new normal (2005–2014) | After entering the new normal (2015–2019) | Class-A cities | Class-B cities |
|---------------------------|---------------|---------------|---------------------------------------------|-------------------------------------------|----------------|----------------|
| Lagged LnUL               | 0.403***      | 0.496***      | 0.279***                                    | 0.856***                                  | 1.499**        | 0.425***       |
| LnEG                      | 0.019*        | −0.104**      | −0.063                                      | 0.028*                                    | −1.378**       | −0.093*        |
| CS                        | 0.038**       | 0.058*        | 0.007                                       | 1.527*                                    | 0.000          |                |
| SI                        | 0.076*        | 0.282**       | 0.064*                                      | 3.243**                                   | 0.006*         |                |
| LnAG                      | 0.039*        | −0.036        | 0.067                                       | 0.367                                     | 0.055*         |                |
| DF                        | −0.017*       | −0.015        | −0.004                                      | −0.105**                                  | −0.160         |                |
| D LnSU                    | −0.148        | 0.295         | −2.239***                                   | −1.608                                    | −2.024         |                |
| LnOP                      | 0.027         | −0.062        | 0.065*                                      | 0.102**                                   | −0.096         |                |
| _cons                     | −0.924***     | −1.842***     | −1.549**                                    | 2.158**                                   | −29.931**      | 0.206***       |
| AR(1)                     | 0.000         | 0.000         | 0.000                                       | 0.062                                     | 0.098          | 0.000          |
| AR(2)                     | 0.427         | 0.214         | 0.915                                       | 0.819                                     | 0.249          | 0.160          |
| Sargan test               | 410.000       | 447.910       | 262.240                                     | 27.940                                    | 139.350        | 316.74         |
| WALD test                 | 10,913.12***  | 9765.45***    | 1356.66***                                 | 5673.21**                                 | 9938.45**      | 2367.81***     |
| N                         | 600           | 600           | 400                                         | 200                                       | 195            | 405            |

The superscripts ***,** and * denote the significance at 1%, 5% and 10% levels, respectively. The values reported for AR(1) and AR(2) are the p-values for the null hypothesis of no one-order and second-order serial correlation the first-differenced residuals.
and is statistically significant ($-0.104, p < 0.05$) when the control variables are introduced into the model, thus implying that economic development is not conducive to boosting urban livability.

Considering that China’s economy has entered a new normal phase during the sample period, which is mainly manifested that the growth rate of China’s economic development has decelerated significantly since 2014, and more attention has been given to the quality and the upgrading of structure (Gao et al. 2019). In view of this, we further divided the sample into two sub-samples of 2005–2014 and 2015–2019, and performed regression analysis on both. According to the regression results, it can be seen that China’s economic development exerts no statistically significant effect on urban livability before entering the new normal phase. This may be due to the fact that China has given more attention to the scale and quantity of economic development in the past, but did not greatly emphasize the ecological environmental effects, which has caused the improvement of urban human settlements to lag behind. Therefore, the supporting effect of economic development on the construction of livable cities is offset by the negative environmental externalities it grants.

However, the impact of economic development on urban livability has altered from negative to positive after entering the new normal phase. Although this coefficient is small, it is statistically significant, thus implying that a higher economic level facilitates urban livability improvement during this period. The reason for this may be that at this stage the country has gradually shifted from pursuing the quantity of economic growth to pursuing the quality of economic development, and has also been constantly promoting the reshaping of urban morphology and enhancement of urban scale guided by the concept of ecological priority and green development.

The difference in city scale may also lead to differences in the above-mentioned effects. Therefore, based on the average value of indicators such as GDP and population size during the sample period, the 40 cities are clustered into two types of samples (A and B) using SPSS 26.0 software. Cluster A includes Shenzhen, Chongqing, Hangzhou, Shanghai, Jinan, Chengdu, Tianjin, Nanjing, Xi’an, Wuhan, Hangzhou, Guangzhou, and Beijing. These cities are basically municipalities directly under the central government and economically developed capital cities. The other 27 cities in the sample form cluster B. The results show that the class-A cities imply a negative and statistically significant impact of economic development on urban livability, indicating that there is no inevitable relationship between the level of urban livability and city scale, and the positive scale effect of cities is not significant.

Moreover, in cities with developed economies and larger scales, economic development exerts a stronger inhibitory effect on urban livability. This also signifies that, in the new era, the Chinese government must further promote the transformation of urban development orientation from the extensive growth of population and economy to the connotation and quality of urban development, and attach more importance to the construction of pleasant ecological space, convenient living space, and harmonious social space. As for the class-B cities, the impact of economic development on urban livability is relatively small, with lower significance. The underlying reason for this is that these cities have relatively small populations and high per capita possession of certain human settlement resources; in addition, they are mostly tourism-oriented cities, which are superior to other cities in terms of environmental construction and beautification.

Impact analysis of the control variables on urban livability

From the perspective of the influence of each control variable, the regression results reveal that there is no statistically significant relationship between industrial structure and urban livability for the entire sample, namely the class-A and class-B cities. However, the sub-sample data set from 2015 to 2019 shows a statistically significant and negative relationship between the two. The reason for this may be that, although the upgrading of the industrial structure possesses improved economic benefits, it has had a certain destructive effect on low-skilled jobs. After entering the new normal phase, there remains a disconnect between the quality of the labor force and the upgrading of the industrial structure in many cities. At the same time, the job market’s preference for highly skilled labor has become more and more apparent (Song and Li 2019). All of these factors cause the employment pressure of many laborers in cities to generally increase, thereby reducing their urban livability. Furthermore, although the percentage of the tertiary industry is increasing each year, the traditional low-end industries within the tertiary industry in many cities still account for a large proportion, which is not conducive to the improvement of livability.

The impact of credit scale on urban livability improvement is statistically significant and positive, as expected, for the entire sample and the sample before entering the new normal phase and for the sample of class-A cities. To a certain extent, the scale of credit reflects the ability of urban residents to pay for housing. In general, the larger the credit scale is, the higher the people’s daily consumption and housing affordability will be, which indirectly drives the rise of urban livability.

The relationship between the level of science and technology and urban livability is positive and statistically significant for the entire sample and for almost all of the samples.
of different periods and types, thus implying that a higher science and technology level can boost urban livability. In recent years, many new technologies and methods, such as artificial intelligence technology, big data technology and storm flood simulation technology, have played important roles in the construction of safe cities, smart cities, and sponge cities, and in improving the quality of urban human settlements.

With regard to financial sufficiency, the entire sample and sample of class-A cities have undergone a negative impact on urban livability, as some local governments often support their fiscal expenditures and urban construction through land transfers due to financial pressure, and have gradually fallen into a situation of “land finance.” However, land finance has a significant negative impact on the city’s total factor productivity. Worse still, this may also stimulate the rise of housing prices, lead to the distortion effect of urban resource allocation, and cause the wage level to deviate from the labor productivity benchmark (Tang et al. 2019), thereby exerting an adverse effect on urban livability.

Neither the entire sample set nor the samples of the class-B cities and 2005–2014 samples show a statistically significant response of urban livability to economic openness. However, in the regression results of the two samples of 2015–2019 and class-A cities, the impact of economic openness on urban livability is positive and statistically significant. With the improvement of environmental regulatory standards, these cities focus more on the introduction of clean, environment-friendly enterprises or foreign investment, thereby contributing to the improvement of local environmental quality.

Robustness checks

In order to testify the reliability of the result of benchmark regression, this study conducts two types of robustness test, namely replacing the core explanation variables and employing another econometric method. The corresponding results are reported in Table 4. The results of benchmark regression have been discussed in Section 4.3.2. The third column in Table 4 is the estimated result after replacing the core explanatory variables. We use the per capita GDP of each city as a substitute variable for economic development, and then perform a SYS-GMM regression. It can be seen that compared with the benchmark regression, the regression results after replacing the explanatory variables are basically unchanged. In addition, the regression results after changing the econometric method were reported in the fourth column. Here, the feasible generalized least squares (FGLS) method was used to estimate Eq. (12) with all the control variables. This method could further correct the impact of the possible heteroscedasticity and autocorrelation of urban individual perturbation terms on the estimation results (Wu et al. 2020). It is found that the estimated coefficient of the economic development (LnEG) becomes larger, but it still has a significant negative impact on the urban livability. The above two types of tests fully demonstrate that the results of this study are robust and reliable.

Conclusions and policy implications

“Livability” signifies the eternal pursuit of ideal urban human settlements. On the basis of sorting out and analyzing the concepts, connotations, and evaluation methods of urban livability, this study established a systematic analysis framework for urban livability from the aspects of evaluation index system construction, spatial–temporal pattern evolution, regional type division, and impact mechanism analysis. The analysis framework provides an effective tool for the comprehensive analysis of quality of urban human settlements in both China and other vast developing countries.

Moreover, an empirical analysis was further carried out based on the panel data of 40 major cities in China from 2005 to 2019. The study’s main findings are as follows. First, the livability level of Chinese major cities has generally shown an upward trend from 2005 to 2019, yet it differs across different dimensions. In particular, the levels of urban security and environmental health are lower than those of the other three dimensions. Second, along the Hu Line, there is a
spatial pattern of east–west differentiation in urban livability. However, little difference in urban livability on both sides of the Bole-Taipei Line is observed. Cities with higher livability are mainly distributed in the first quadrant, composed of the above-mentioned two lines. Third, the 40 major Chinese cities were divided into five types, and there are obvious differences in the levels, spatial distribution, and improvement directions across the different types. Finally, the results of quantitative investigation indicate that for the entire sample base, the higher economic development level, as measured by labor productivity per capita, exerts a negative inhibitory effect on the boost of urban livability. In addition, when the samples were divided into diverse sub-samples, the above-mentioned logical effect showed obvious heterogeneity. This demonstrated that the positive effect of economy growth on urban livability was more statically significant for the Chinese cities after entering the new normal phase than that of not.

The conclusion of this study carries broad policy implications. On the one hand, efforts should be made to inspect the correlation between urban livability and economic development more comprehensively and scientifically. Despite the fact that high-quality economic development can provide a solid material foundation for the construction of livable cities, do not take it for granted that they are synchronized, coordinated, and well matched. It is found that the economic growth has a certain inhibitory effect on urban livability in China. Similar conclusions have also been reached in other empirical studies or places (Chatterjee, et al. 2020; Mouratidis 2020; Tang et al. 2017). Of course, this is not due to economic development itself, but urban development and construction model in the past should be further optimized and improved. Therefore, it is necessary for China and other developing countries to seek a complementary viewpoint of viewing development comprehensively in the future development. In addition to continuously consolidating the foundation for economic development, more attentions should be paid to the benign matching of urban economy, population, resources, and environmental endowments, to increase the supply of ecologically green, civilized, and harmonious environments in cities, so as to fully demonstrate the original mission of “Better City, Better Life.”

On the other hand, scientifically exploring determinants of what makes cities livable under different national or regional contexts can provide targeted insights into the improvement of urban human settlements. Both similarities and differences between different urban contexts should be considered in ways that will increase quality of life in cities by making better use of the main livability determinants in each city as well as learning from what makes other cities more livable. For example, based on empirical research results in China, it is necessary to realize that the rapid development and rising proportion of the tertiary industry cannot be regarded as the only way to address environmental issues. Efforts should be to unify the three aspects of overall improvement of the workers’ quality, the service industry moving toward the mid- to high-end of the value chain, and the wage income commensurate with labor productivity. In addition, there remains a general trend of promoting high-quality urban development through a high level of opening up. However, attention must be paid to the optimization of the structure of foreign investment. In particular, cities in the central and western regions of China should promote the shift of foreign investment and foreign trade to high-tech and clean fields, thereby escaping the predicament of “pollution shelter hypothesis” and realizing the “pollution halo hypothesis”.

Finally, there are still some limitations that need to be improved in this paper. On the one hand, livability is a multidimensional concept. The construction of the evaluation index system is restricted by the availability of data and the measurability of indicators. Therefore, the connotation of urban livability may not be fully explained and comprehensively measured. On the other hand, due to the lack of raw data for many cities, we only selected 40 cities as samples in our empirical research, so the results obtained may have certain limitations. However, through these 40 large and medium-sized cities, we can obtain an understanding of the general outlook of the livable cities–construction process in China. With the gradual improvement of national and local statistical data, we will further deepen these deficiencies. In addition, this study found that the impact of economic development on livability is heterogeneous due to different urban scales. Therefore, how to determine the optimal scale of urban development from the perspective of livability is also a topic worthy of further discussion and follow-up research.

Appendix

This is the derivation for the calculation formula of the combined weight method. In Sect. 3.2, we have obtained the objective weight (w_{ij}) and the subjective weight (w_{ij}) of each indicator. Now, we need to calculate the combined weight (w_{j}) based on the w_{ij} and w_{ij}.

First, according to the relative entropy formula:

\[ H_1 = \sum_{j=1}^{n} w_j \ln \left( \frac{w_j}{w_{ij}} \right), H_2 = \sum_{j=1}^{n} w_j \ln \left( \frac{w_j}{w_{ij}} \right) \]

The total relative entropy can be expressed as follows:

\[ F = H_1 + H_2 = \sum_{j=1}^{n} w_j (\ln w_j - \ln w_{ij}) + \sum_{j=1}^{n} w_j (\ln w_j - \ln w_{ij}), \sum_{j=1}^{n} w_j = 1 \]

Then, according to the principle of minimum relative entropy, when the total relative entropy is minimum, w_{j} is
the closest to \( w_{1j} \) and \( w_{2j} \). Next, the minimum value of \( F \) can be calculated:

Assuming \( \varphi (w_1, w_1, \ldots, w_n) = \sum_{j=1}^{n} w_j - 1 = 0 \), we can construct a Lagrangian function:

\[
L(w_1, w_1, \ldots, w_n, \lambda) = F(w_1, w_1, \ldots, w_n) + \lambda \varphi(w_1, w_1, \ldots, w_n) \tag{15}
\]

Subsequently, according to the Lagrange Multiplier Method, we can get:

\[
\frac{\partial L}{\partial w_j} = 1 + \ln w_j = \ln w_{1j} + 1 + \ln w_j - \ln w_{2j} + \lambda = 0
\]

\[
\frac{\partial L}{\partial \lambda} = \varphi(w_1, w_1, \ldots, w_n) = \sum_{j=1}^{n} w_j - 1 = 0
\tag{16}
\]

Arranging the first equation, we can get:

\[
w_j = e^{\frac{\ln w_{1j} + \ln w_{2j} - 1 - 2}{2}} = e^{-\frac{1}{2}} \sqrt{w_{1j} \times w_{2j}}
\tag{17}
\]

Substituting Eq. (18) into Eq. (17), we can get:

\[
\sum_{j=1}^{n} w_j = \sum_{j=1}^{n} e^{-\frac{1}{2}} \sqrt{w_{1j} \times w_{2j}} = e^{-\frac{1}{2}} \sum_{j=1}^{n} \sqrt{w_{1j} \times w_{2j}} = 1
\tag{18}
\]

Therefore:

\[
e^{-\frac{1}{2}} = \frac{1}{\sum_{j=1}^{n} \sqrt{w_{1j} \times w_{2j}}} \tag{19}
\]

Substituting Eq. (20) into Eq. (18), we can know that \( F \) can obtain an extreme value when \( w_j = \sqrt{\frac{w_{1j} \times w_{2j}}{\sum_{j=1}^{n} \sqrt{w_{1j} \times w_{2j}}}} \). Combined with the actual situation, this extreme value should be the minimum value.

In this way, we can get the final combined weight (\( w_j \)) of each indicator.

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**Data availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

**Ethical approval** This research project has been approved by the Ethics Committee of Nanjing University of Science and Technology.

**Consent to participate** Written informed consent for publication was obtained from all the authors.

**Consent for publication** The author confirms that the article described has not been published before; not considering publishing elsewhere; its publication has been approved by all the co-authors; Its publication has been approved (acquired or publicly approved) by the responsible authority of the institution where it works. The author agrees to publish in the following journals, and agrees to publish articles in the corresponding English journals of Environmental Science and Pollution Research. If the article is accepted for publication, the copyright of English articles will be transferred to Environmental Science and Pollution Research. The author declare that his contribution is original and that he has full rights to receive this grant. The author requests and assumes responsibility for publishing this material on behalf of all and all the co-authors. Copyright transfer covers the exclusive right to copy and distribute articles, including printed matter, translation, photo reproduction, microform, electronic form (offline, online), or any other reproduction of similar nature.

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