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Urban Comprehensive Carrying Capacity and Urbanization in Northeast China

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Abstract: The scientific evaluation and identification of the relationship between urban comprehensive carrying capacity and urbanization in Northeast China, a famous old industrial base, is an important basis for realizing the overall revitalization of the region. Using a panel data set of 34 prefecture-level cities in Northeast China from 2003 to 2019, this study constructs an ordinary panel data model to identify the relationship between urban comprehensive carrying capacity and urbanization. The results show that urbanization has significantly positive effects on urban comprehensive carrying capacity, and there is a significant inverted U-shaped curve relationship between urban comprehensive carrying capacity and comprehensive urbanization in Northeast China, especially in the shrinking cites. In addition, the economic urbanization variables of the fixed-asset investment, the total retail sales of social consumer goods, and the social urbanization variable of internet users play significantly important roles in forming of the inverted U-shaped curve relationship with the urban comprehensive carrying capacity of the shrinking cities in Northeast China. Hence, innovation-driven economic regrowth, promoting equalization of basic public services, alleviating talent outflow, and strengthening the leading roles of the core cities are effective measures for improving urban comprehensive carrying capacity and urbanization quality in Northeast China.

Keywords: sustainable urban development; urban comprehensive carrying capacity; urbanization; old industrial base; panel data econometric model

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1. Introduction

Urbanization is one of the most important human activities affecting the Earth [1] and is also a dynamic, multiscalar, and complex process [2,3]. Urbanization includes not only the agglomeration of population in cities but also changes in the mode of economic development, life, and land use [4]. Urbanization is crucial for social and economic transformation, prosperity, and economic development. However, urbanization has inevitably resulted in land shortages, an insufficient supply of public services, environmental pollution, and other 'city diseases' [5]. Many cities globally are under the threat of being overloaded, and the carrying capacity of cities is unable to support the scale of urban development [6,7]. As the world continues to urbanize, carrying capacity has become a major concern and a widespread challenge facing sustainable urban development [8].

Urban carrying capacity implies the level of population or development that can be sustained in an area without adversely affecting the area beyond an acceptable level [7,9], or refers to the maximum load that a city can survive in a given environment without any damage and can fully consider the pressure factors of resources and services with the concept of sustainable development [10]. Urban carrying capacity has been used as an essential barometer and scale of sustainable urban development [11]. Previous studies

have contributed to single-element carrying capacity research, which mainly focuses on land [12,13], water [14–16], ecological environment [17,18], and culture [19,20].

Urban sustainability necessitates harmonious and balanced relationships between three environments: the eco-physical, the social, and the economic environments [21]. In fact, urban carrying capacity is not a static and fixed value but a dynamic and improvable value with changes in economics, technology, human preferences, and society [22,23]. The urban comprehensive carrying capacity of integrated social, economic, and environmental aspects should be considered and strengthened. Some achievements have been made in this field. For example, Oh et al. established an integrated framework including energy, green areas, roads, subway systems, water supplies, sewage treatment, and waste treatment for assessing Gangnam District's carrying capacity, one of the most densely developed districts in Seoul, South Korea [7]. Meanwhile, recent studies particularly address the space–time complexity and their nonlinear relationship between urbanization and the eco-environment [24,25].

However, most current research focuses on static studies, and the dynamic UCC research is insufficient [26]. In addition, the current methodology does not seem to have transitioned from case studies to a mature econometric model consensus, and the exact quantitative relationship between urbanization development and its comprehensive carrying capacity is not sufficient [27]. Importantly, current UCC research is limited to rapidly urbanizing areas such as the Guangdong–Hong Kong–Macao Greater Bay Area, and Tehran metropolis [9,28], but there is a noticeable lack of adequate analyses conducted in shrinking cities [29], such as Northeast China, one of the most important old industrial bases with the worst urban shrinkage in China [30]. Although urban growth is an uncontested reality in both developed and developing countries, urban shrinkage is no less a reality, despite being immersed within the ubiquitous discourse of growth [31]. Urban shrinkage is an increasingly important fact and a major challenge for future urban policy and urban research [32], but little is understood about all its manifestations [33]. Hence, sustainable urban development should also consider shrinking cities, and the comprehensive carrying capacity integrating socioeconomic, environmental and livelihood factors in the context of urban shrinkage should be given enough attention and discussed in depth [34,35].

To date, there has not been an in-depth discussion and analysis of the relationship between urban comprehensive carrying capacity and urbanization in Northeast China, resulting in difficulty in formulating a reasonable revitalization policy to alleviate or avoid shrinkage and providing a feasible path for sustainable urban development in the old industrial base. Hence, a comprehensive and systematic scientific understanding of the relationship between urban comprehensive carrying capacity and urbanization in Northeast China has become an urgent practical need for sustainable urban development and their all-round recovery and revitalization. This study develops the composite evaluation index system of urban comprehensive carrying capacity and comprehensive urbanization and uses them to comprehensively and accurately assess urban sustainable development in Northeast China. Then, based on panel data econometric models and the two key variables, this study explores the econometric relationship between urban comprehensive carrying capacity and urbanization in Northeast China from 2003 to 2019, which makes up for the lack of dynamics in current carrying capacity research. Additionally, it makes up for the fact that the current carrying capacity research focuses more on rapidly urbanizing areas and ignores declining and shrinking regions. This research not only expands the perspective and breadth from the scientific level but also provides scientific guidance for the sustainable development of shrinking old industrial bases.

2. Analysis Framework

Urbanization is an important driving force in the Anthropocene and one of the most important manifestations of the development and evolution of human society with complex evolution and transformation processes, including large-scale population migration, urban land expansion, industrial restructuring, capital agglomeration, and changes in

cultural and consumption habits [36]. Urban comprehensive carrying capacity refers to the threshold value of the scale and intensity of various human activities that urban resources can carry under a certain period of time; spatial area; and social, economic, and ecological environment conditions [6,7]. Urbanization has a coercive or facilitative effect on urban support systems such as the ecological environment through population growth, economic development, energy consumption, technological progress, urban management, and expansion of construction land. The urban support system also exerts constraints or bearing effects on urban development through resource carrying, environmental capacity, ecosystem services, environmental equity, institutions, culture, and policy intervention. The two systems have a competitive and cooperative relationship that includes mutual inclusion and the unity of opposites (Figure 1).

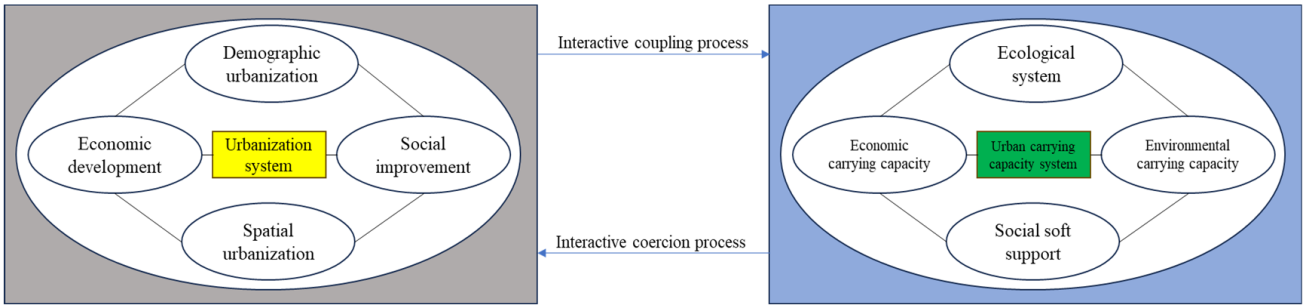

Figure 1. Interactive mechanism between urbanization and comprehensive urban carrying capacity.

3. Materials and Methods

3.1. Study Area

Northeast China has an important strategic position in maintaining national security, food security, ecological security, energy security, and industrial security and is of vital importance in China's modernization. Northeast China is the largest old industrial base in China and is persistently influenced by the past planned economy, resulting in being locked into concentrated heavy industry made up of state-owned enterprises, and failing to innovate and transform its critical industry of manufacturing since the beginning of the 1990s. The region is facing problems similar to those of the US's rustbelt and Germany's Ruhr area, such as a declining economy, job loss, and population outflow [37,38]. An amount of 65.38% of shrinking cities in Northeast China were identified as absolutely shrinking cities, suffering simultaneously from economic and demographic decline [37]. Compared with 2010, the population growth rate of Northeast China in 2020 was −10.04%, among which the population growth rate of Heilongjiang Province was −16.87%, becoming the province with the most serious negative population growth in the country [39]. In addition, 33 of the 38 prefecture-level cities in Northeast China have negative population growth [39]. The three northeastern provinces of Liaoning, Jilin, and Heilongjiang had ushered in an era of sustained and stable negative population growth before 2020 [40]. Northeast China is experiencing the worst and long-term urban shrinkage [35,37], which has lost its leading place and become a lagging region [41].

Northeast China consists of Liaoning Province, Jilin Province, Heilongjiang Province, and the eastern part of the Inner Mongolia Autonomous Region (including Hulunbuir City, Xing'an League, Tongliao City, Chifeng City, and Xilingol League), with an area of 1.26×10^6 km^2 and a population of 120 million. In this study, we adopt a narrow concept of Northeast China consisting of Liaoning Province, Jilin Province, and Heilongjiang Province. Due to the severe lack of data on Yanbian of Jilin Province and Daxinganling of Heilongjiang Province, to avoid analysis error, this study removes them, and only 34 prefectural-level cities are chosen to explore the relationship between urban comprehensive carrying capacity and urbanization (Figure 2). Of the 34 prefecture-level cities, six cities, Shenyang, Yingkou, Panjin, Chaoyang, Changchun, and Harbin, are not shrinking cities, and the re-

maining 28 cities are in different urban shrinking stages [42]. Of the six nonshrinking cities, Shenyang, Yingkou, Panjin, and Chaoyang are located in Liaoning Province; Shenyang is its provincial capital; and Changchun and Harbin are the provincial capitals of Jilin Province and Heilongjiang Province, respectively. Of the remaining 28 shrinking cities, 10 cities are located in Liaoning, seven cities are located in Jilin, and 11 cities are located in Heilongjiang, respectively.

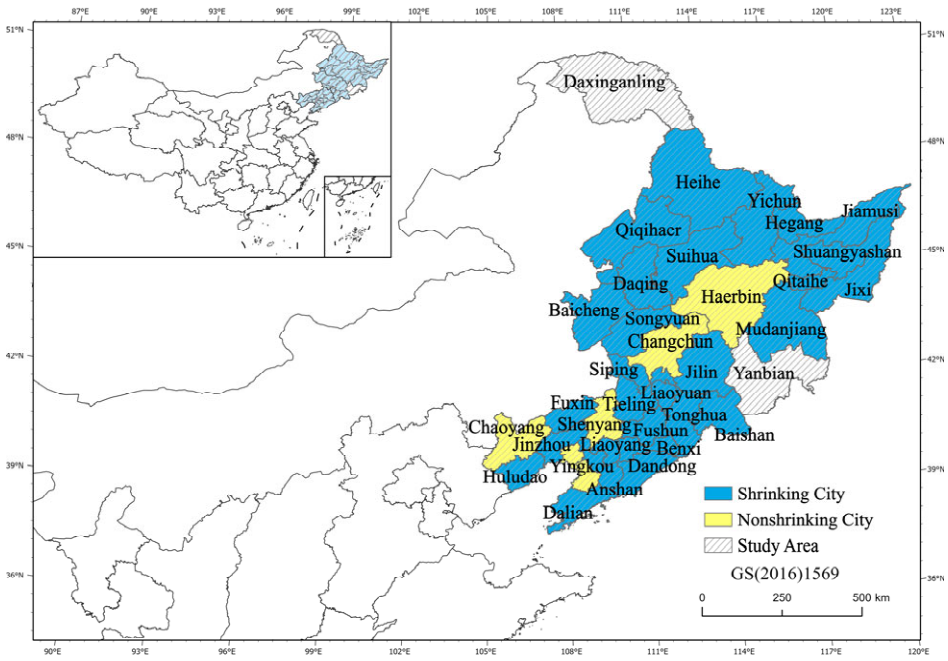

Figure 2. The study area.

3.2. Data Source

The raw data used in this study are derived from the China City Statistical Yearbook, the China Regional Economy Statistical Yearbook; the statistical yearbooks of Liaoning Province, Jilin Province, and Heilongjiang Province; and the statistical yearbooks and the national economic and social development statistical bulletins of the prefecture-level cities under the jurisdiction of the three provinces. Some missing values are extrapolated using an interpolation method.

3.3. Multi-Index Comprehensive Evaluation Framework

3.3.1. Urban Comprehensive Carrying Capacity Evaluation Indicator System

Carrying capacity would be determined by a wide range of natural, economic, environmental, demographic, and political factors [19,43]. Oh et al. identified energy systems, green areas, roads, subway systems, water supplies, sewage treatment, and waste treatment as decisive factors of urban comprehensive carrying capacity [7]. Wei et al. developed a quantitative-based practical urban comprehensive carrying capacity assessment framework to monitor and evaluate sustainable urban development, including environmental and natural resources, infrastructural and urban services, policy perception, institutional setting, and societal supporting capacity [11]. Then, they chose economic, resource, environmental, infrastructural, and transport subcategories to build an index system to evaluate the urban comprehensive carrying capacity of China's megacities [44]. Su et al. selected environment, resources, infrastructure, science and technology, social culture, urban security, ecological civilization, and public services to evaluate urban comprehensive carrying capacity [10]. Shao et al. used economic, social, environmental, and transportation indicators to estimate carrying capacity [28]. Combined with the above research achievements and the actual situation of Northeast China, the evaluation indicators are chosen when they

are valuable in academic research and practical application [45,46]. This study develops an integrated urban comprehensive carrying capacity evaluation index system of social, economic, and resource and environmental indicators with a pressure-state-response framework (Table 1). The index system includes 32 indicators, with 10 social carrying capacity indicators, 11 economic carrying capacity indicators, and 11 resource and environmental carrying capacity indicators.

Table 1. Urban comprehensive carrying capacity evaluation indicator system of prefecture-level cities in Northeast China.

System Level	First Level Index	Basic Level Index
Social carrying capacity	Pressure	Annual natural population growth rate (‰)
		Urban registered unemployed population to urban employed population (%)
		Teacher/student ratio in primary and secondary schools
	State	Urban population (% of total)
		Number of medical beds per 10,000 persons
		Number of public library books per 100 persons
	Response	Education expenditure (% of fiscal budget expenditure)
		Number of doctors per 10,000 persons
		Urban employed population (% of total population)
		Number enrolled in higher education per 10,000 persons
Economic carrying capacity	Pressure	Secondary industry GDP (% of total GDP)
		Urban construction land (% of urban area)
		Built-up area (km^2)
	State	GDP per capita (Yuan)
		Employees in secondary and tertiary industries to total employment (%)
		GDP per area of land (10^4 Yuan·km^{-2})
	Response	Average salary of employees (Yuan)
		Fixed-asset investment (% of GDP)
		Science and technology expenditure (% of fiscal expenditure)
		Foreign direct investment (% of GDP)
		Tertiary industry GDP (% of total GDP)
Resource and environmental carrying capacity	Pressure	Industrial wastewater discharged per 10,000 Yuan GDP (ton)
		Industrial sulfur dioxide emissions per 10,000 Yuan GDP (kg)
		Industrial soot (dust) emissions per 10,000 Yuan GDP (kg)
	State	Electricity consumption per 10,000 Yuan GDP (kWh)
		Natural and coal gas supply per 10,000 Yuan GDP (m^3)
		Liquefied petroleum gas supply per 10,000 Yuan GDP (kg)
		Per capita public green areas (m^2)
	Response	Green coverage rate of urban built-up areas (%)
		Harmless treatment rate of domestic waste (%)
		Ratio of general industrial solid waste utilized (%)
		Centralized treatment rate of sewage treatment plants (%)

3.3.2. Urbanization Level Evaluation Indicator System

The measurement of urbanization level mainly includes the single index and comprehensive index methods. Most existing studies use the proportion of the urban population to measure the urbanization level, but the single index method measures only the quantitative process of the flow of the rural population to cities, which makes it difficult to accurately reflect the rich connotations of urbanization [47,48]. The comprehensive index evaluation method is widely used to assess the status of urban development [49,50]. The comprehensive index system can more comprehensively and completely monitor the urbanization process and clarify the coordinated evolution of population urbanization and regional landscape, economic structure, and living methods [51]. Referring to existing research achievements and combining the actual situation in Northeast China [52,53], we propose an index system composed of the four dimensions of demographic, economic, social, and

spatial urbanization to evaluate the comprehensive urbanization level of Northeast China (Table 2). The index system involves four categories and 17 subcategories.

Table 2. Urbanization level evaluation indicator system of prefecture-level cities in Northeast China.

First-Level Index	Basic-Level Index	Indicator Abbrivation
Demographic urbanization	Urban population (% of total)	*urba_rate*
	Population density (person·km^{-2})	*pop_dens*
	Employment in tertiary industry (% of total employment)	*terti_emp*
	Number enrolled in higher education per 10,000 persons	*colle_stud*
Economic urbanization	GDP per capita (Yuan)	*gdp_per*
	Fixed-asset investment (10^8 Yuan)	*fixed_inves*
	Industrial output value of enterprises above designated size (10^8 Yuan)	*indus_value*
	Total profits of enterprises above designated size (10^8 Yuan)	*profit*
	Total retail sales of social consumer goods (10^8 Yuan)	*retail_sales*
Social urbanization	Number of doctors per 10,000 persons	*medi_staff*
	Number of public library books per 100 persons	*pub_book*
	Number of medical beds per 10,000 persons	*hosp_bed*
	Number of public transport vehicles per 10,000 persons	*pub_trans*
	Internet users per 100 persons	*inter_user*
Spatial urbanization (0.061)	Built-up area (km^2)	*built_area*
	Urban construction land (% of urban area)	*cons_land*
	Per capita area of paved roads (m^2/person)	*urb_road*

3.4. Empirical Model

The environmental modernization theory indicates that urbanization is a process of social transformation, which is a vital sign of development [54], so the widely known environmental urbanization Kuznet curve (EUKV) is examined [55,56]. In other words, at the initial stage of urbanization, the environmental impacts are intensified due to the extensive development mode, and as societies continue to grow into higher stages of development and urbanization enters a new development stage, societies explore ways to become more ecologically sustainable. Generally, the environmental Kuznets curve (EUKC) model and STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology) are used to describe how economic activities affect the environment and investigate the implications of human action [57]. STIRPAT stands for stochastic (ST) detrimental impacts (I) by regression (R) by population (P), GDP per capita or affluence (A), and technology (T). Meanwhile, researchers add urbanization instead of population for (P) and governance to incorporate behaviors (B). Based on the above theoretical model, this study develops a basic ordinary panel data model that includes urban comprehensive carrying capacity and urbanization. To reduce the variance and influence degree of heteroscedasticity [58], pairs of variables are used to investigate the relationship between urban comprehensive carrying capacity and urbanization, as shown in Equation (1):

$$total\_ucc_{it} = \beta_1 total\_urb_{it} + \beta_2 (total\_urb_{it})^2 + \varphi_{1i} x_{it} + \alpha_{1i} + \gamma_{1t} + \varepsilon_{it} \quad (1)$$

where i represents prefecture-level cities in Northeast China; t refers to the time of year; *total_ucc* denotes the urban comprehensive carrying capacity; and *total_urb* is the urbanization level. This study also introduces a quadratic term of urbanization (*total_urb*2) to test whether an EUKC curve relationship exists between urban comprehensive carrying capacity and urbanization; β_1 and β_2 represent estimated parameters; α_i and γ_t are the individual effect and time effect, respectively; ε_{it} represents the random disturbance term; and x_{it} is a vector of control variables that affect the urban comprehensive carrying capacity. In this study, the per-capita gross domestic product (GDP) (*gdp_per*), the proportion of tertiary industry in GDP (*thir_indus*), the proportion of foreign direct investment (FDI) out of GDP (*fdi_gdp*), and the general solid waste treatment rate (*uti_solid_waste*) are chosen

as the control variables, because the urban comprehensive carrying capacity is not only affected by internal factors such as resource, environmental, and socioeconomic systems, but also by external factors such as economic growth, industrial structure, government regulation, and governance ability [59,60].

3.5. Data Processing

First, the calculation of the urban comprehensive carrying capacity index and urbanization index involves dimensionless standardization of the original data [44]. Second, the improved entropy method is used in the objective weighting method to avoid the influence of human factors and to make the evaluation index weight more scientific [61,62]. Finally, each indicator is multiplied by its normalized value with the corresponding weight, and then the value of each dimension can be evaluated to express the three dimensions of urban comprehensive carrying capacity and the four dimensions of urbanization for Northeast China.

The urban comprehensive carrying capacity index and urbanization index are both between 0 and 1. Within this value range, the closer the value is to 1, the closer the comprehensive carrying capacity and urbanization level of the region are to the optimal state. At present, a unified standard for urban comprehensive carrying capacity and urbanization classification has not yet been formed. Based on relevant research results [63], this article uses the non-equidistant division method to divide the urban comprehensive carrying capacity index and urbanization level index into five levels: (0, 0.3] represents lower carrying capacity and urbanization level, (0.3, 0.4] represents low carrying capacity and urbanization level, (0.4, 0.5] represents medium carrying capacity and urbanization level, (0.5, 0.7] represents high carrying capacity and urbanization level, and (0.7, 1) represents highest carrying capacity and urbanization level.

In addition, to avoid spurious regression resulting from a unit root of the dependent variable, hypothesis testing (HT); Im, Pesaran, and Shin (IPS); Levin–Lin–Chu (LLC); and Fisher-type tests are used to judge the stationarity of the variable. It is found that the initial form and logarithmic form of the variable are stationary. Importantly, the variables used in this study pass the variable inflation factor (VIF) collinearity test and Hausman specification endogenous test.

4. Empirical Analysis and Discussion

4.1. Spatiotemporal Changes in Urban Comprehensive Carrying Capacity in Northeast China

The urban comprehensive carrying capacity (*total_ucc*) of the 34 prefecture-level cities in Northeast China gradually improves from 2003 to 2019, with Shenyang and Dalian performing best, followed by Harbin and Changchun (Figure 3). However, most cities are located at lower and low carrying capacity levels, and only Shenyang, Dalian, Harbin, and Changchun have a moderate carrying capacity in some years. However, for regions with rapid economic development with complex urban shrinkage [64], their comprehensive carrying capacity shows different development trends. For example, the comprehensive carrying capacity of most cities in the Guangdong–Hong Kong–Macao Greater Bay Area showed a downward trend [65], while the carrying capacity of the Yangtze River Economic Belt of China is gradually improving [66]. Furthermore, the performance of the carrying capacity of the nonshrinking cities is better than that of the shrinking cities in Northeast China (Table 3). Research has shown that urban shrinkage has exacerbated air pollution in Northeast China [67]. Figure 4 shows the urban comprehensive carrying capacity spatial pattern of the 34 prefecture-level cities in 2003, 2008, 2014, and 2019; the figure confirms that the cities with high urban comprehensive carrying capacity performance are gathered along the Harbin–Dalian High-speed Railway Line and mostly correspond to the provincial capital cities, gradually increasing from the north to the south of Northeast China.

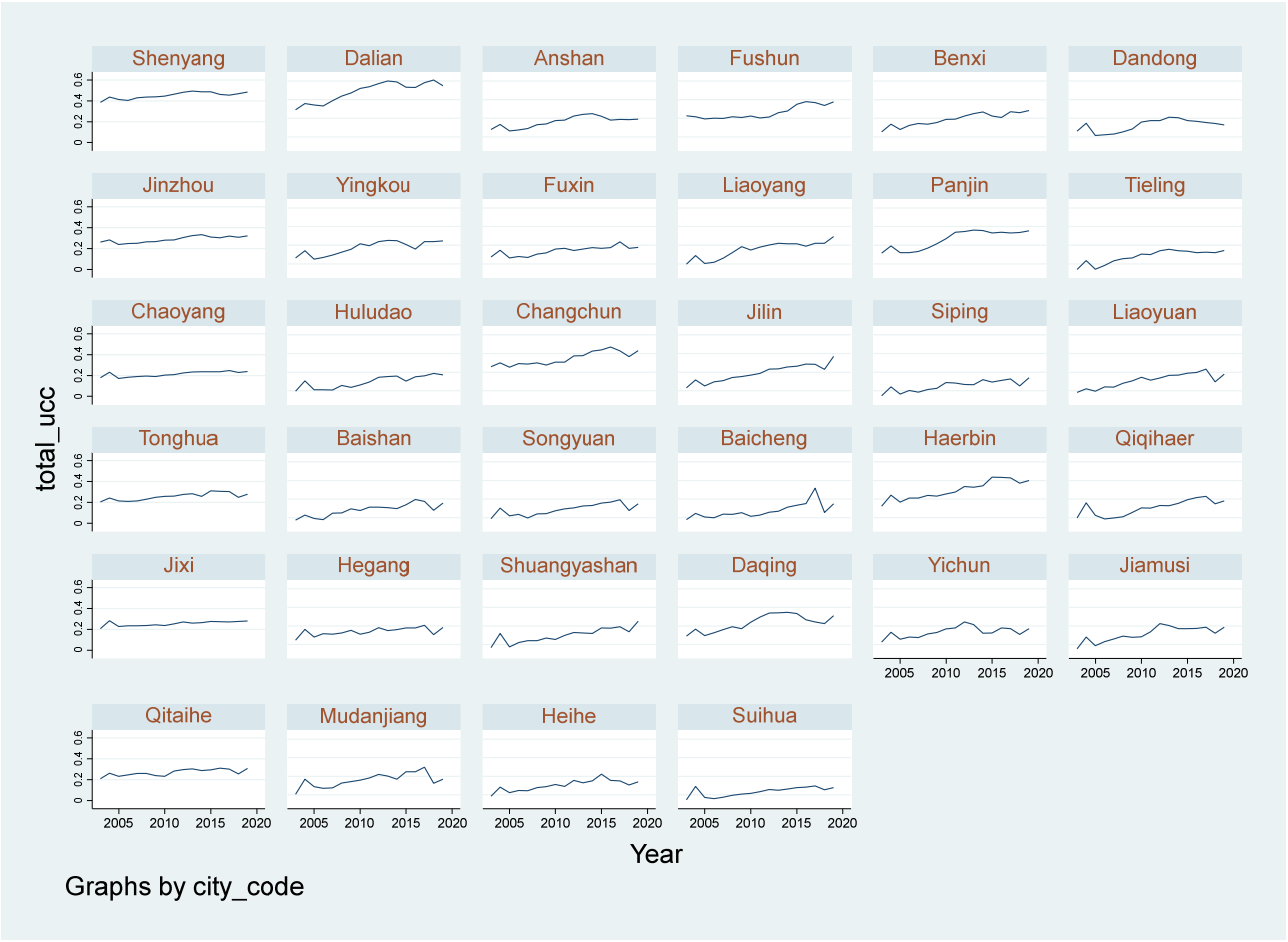

Figure 3. Urban comprehensive carrying capacity (*total_ucc*) change of 34 prefecture-level cities in Northeast China from 2003 to 2019.

Table 3. Carrying capacity of the nonshrinking and shrinking cities in Northeast China.

City Type	Variable	Obs	Mean	Std. Dev.	Min	Max
Nonshrinking cities	*total_ucc*	102	0.334	0.083	0.172	0.494
	scc	102	0.094	0.039	0.033	0.166
	ecc	102	0.107	0.032	0.053	0.179
	recc	102	0.132	0.021	0.083	0.170
Shrinking cities	*total_ucc*	476	0.271	0.054	0.170	0.506
	scc	476	0.069	0.020	0.029	0.160
	ecc	476	0.084	0.026	0.043	0.228
	recc	476	0.117	0.023	0.060	0.228

Notes: *total_ucc* = urban comprehensive carrying capacity; *scc* = urban social carrying capacity; *ecc* = urban economic carrying capacity; *recc* = urban resource and environmental carrying capacity; Obs = observation; Std. Dev. = standard deviation; Min = Minimum value; Max = Maximum value.

On the other hand, the four kinds of carrying capacities began to decline in 2014 and then recovered slowly up to approximately 2016. That is, the first round of the Northeast China Revitalization Policy implemented from 2003 to 2015 promoted the improvement in the carrying capacity of the region, but the policy effect was maintained only until approximately 2013 [68]. To overcome this phenomenon, China started the second round of the Northeast China Revitalization Policy in 2016, and the carrying capacity of the region stopped falling and rebounded. Importantly, the times corresponding to the urban comprehensive carrying capacity changing points are very consistent with the times of the implementation of the Northeast China Revitalization Policy, which may prove that

the development of Northeast China seriously depends on the implementation of relevant national policies and that the endogenous dynamic mechanism of sustainable development has not been fully formed in the region [69].

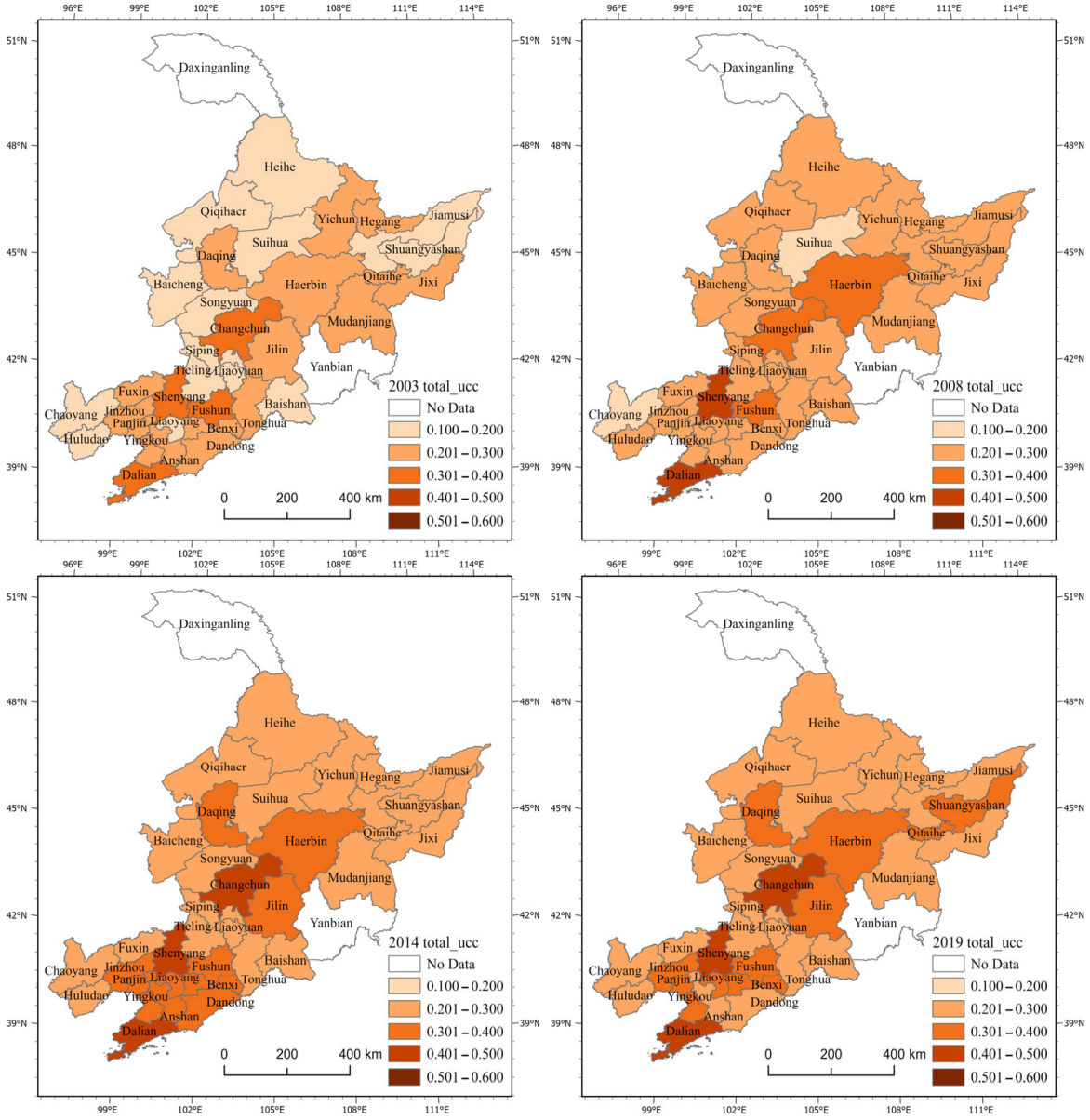

Figure 4. Spatial pattern of urban comprehensive carrying capacity (*total_ucc*) in 2003, 2008, 2014, and 2019 in Northeast China.

4.2. Spatiotemporal Changes in Urbanization Level in Northeast China

The urbanization level (*total_urb*) in Northeast China improves gradually from 2003 to 2019 (Figure 5), but most cities have a lower urbanization level. Only the four provincial capital and subprovincial cities of Shenyang, Dalian, Changchun, and Haerbin have a moderate urban development level in some years. The worst urbanization performance is exhibited by Chaoyang and Tieling of Liaoning, indicating that the polarization of urbanization quality in Liaoning is more significant than those in the other two provinces, just as China's urbanization presents obvious characteristics of hierarchical differences and regional imbalance, and regional development differences are an important factor leading to urban shrinkage. The indexes of the *total_urb*, the demographic urbanization level (*dem_urb*), the economic urbanization level (*eco_urb*), and the social urbanization level

(*soc_urb*) of the nonshrinking cities are higher than those of the shrinking cities, while the index of the spatial urbanization level (*spa_urb*) is just on the contrary (Table 4), indicating that the spatial layout of the nonshrinking cities has a lot of room for optimization. More importantly, it shows that the urbanization quality of the shrinking cities in Northeast China faces a comprehensive and systematic severe challenge. Figure 6 shows the urbanization spatial pattern of the 34 cities in 2003, 2008, 2014, and 2019. It reveals that the spatial pattern of urbanization tends to be unevenly distributed and that the cities with the highest urbanization level, such as Harbin, Changchun, Shenyang, and Dalian, are also concentrated along the Harbin–Dalian High-speed Railway Line, which is consistent with the trend of the urban comprehensive carrying capacity distribution.

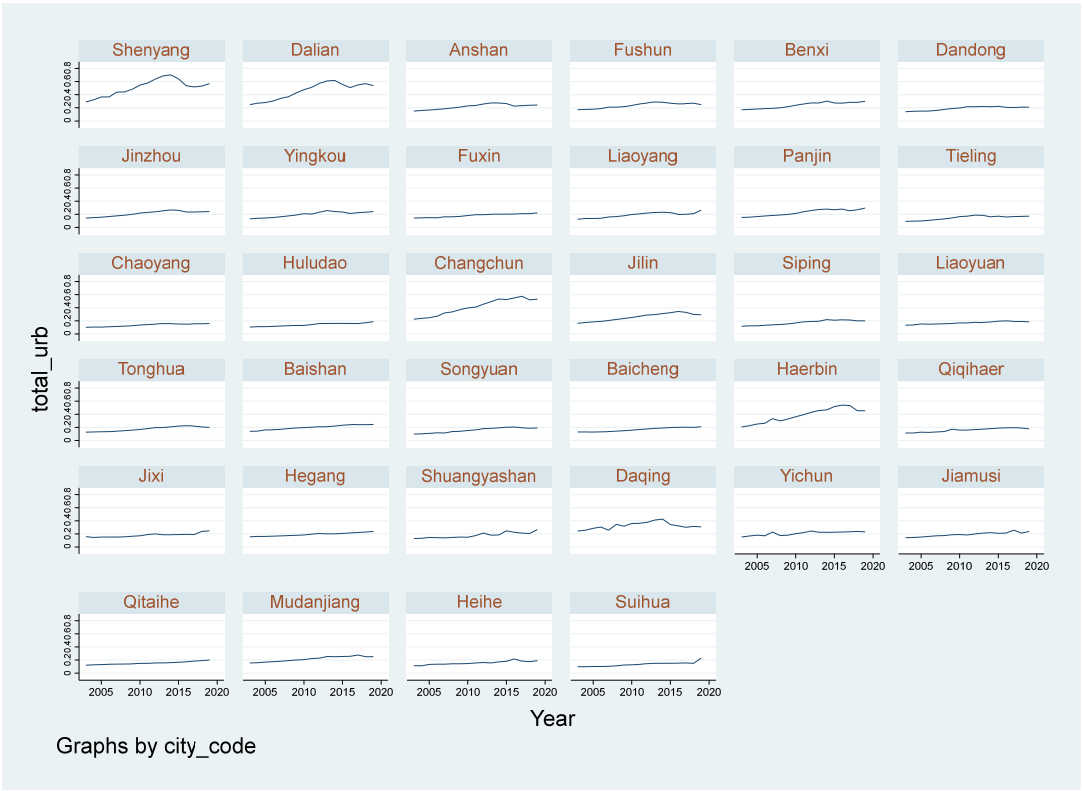

Figure 5. Urbanization level (*total_urb*) change of 34 prefecture-level cities in Northeast China from 2003 to 2019.

Table 4. Urbanization level of the nonshrinking and shrinking cities in Northeast China.

City Type	Variable	Obs	Mean	Std. Dev.	Min	Max
Nonshrinking cities	*total_urb*	102	0.311	0.158	0.102	0.702
	dem_urb	102	0.103	0.050	0.041	0.190
	eco_urb	102	0.121	0.099	0.007	0.406
	soc_urb	102	0.063	0.023	0.02	0.121
	spa_urb	102	0.023	0.004	0.014	0.031
Shrinking cities	*total_urb*	476	0.201	0.075	0.095	0.618
	dem_urb	476	0.077	0.021	0.033	0.157
	eco_urb	476	0.048	0.049	0.006	0.367
	soc_urb	476	0.048	0.021	0.007	0.133
	spa_urb	476	0.029	0.004	0.013	0.060

Notes: *total_urb* = comprehensive urbanization level; *dem_urb* = demographic urbanization level; *eco_urb* = economic urbanization level; *soc_urb* = social urbanization level; *spa_urb* = spatial urbanization level; Obs = observation; Std. Dev. = standard deviation; Min = Minimum value; Max = Maximum value.

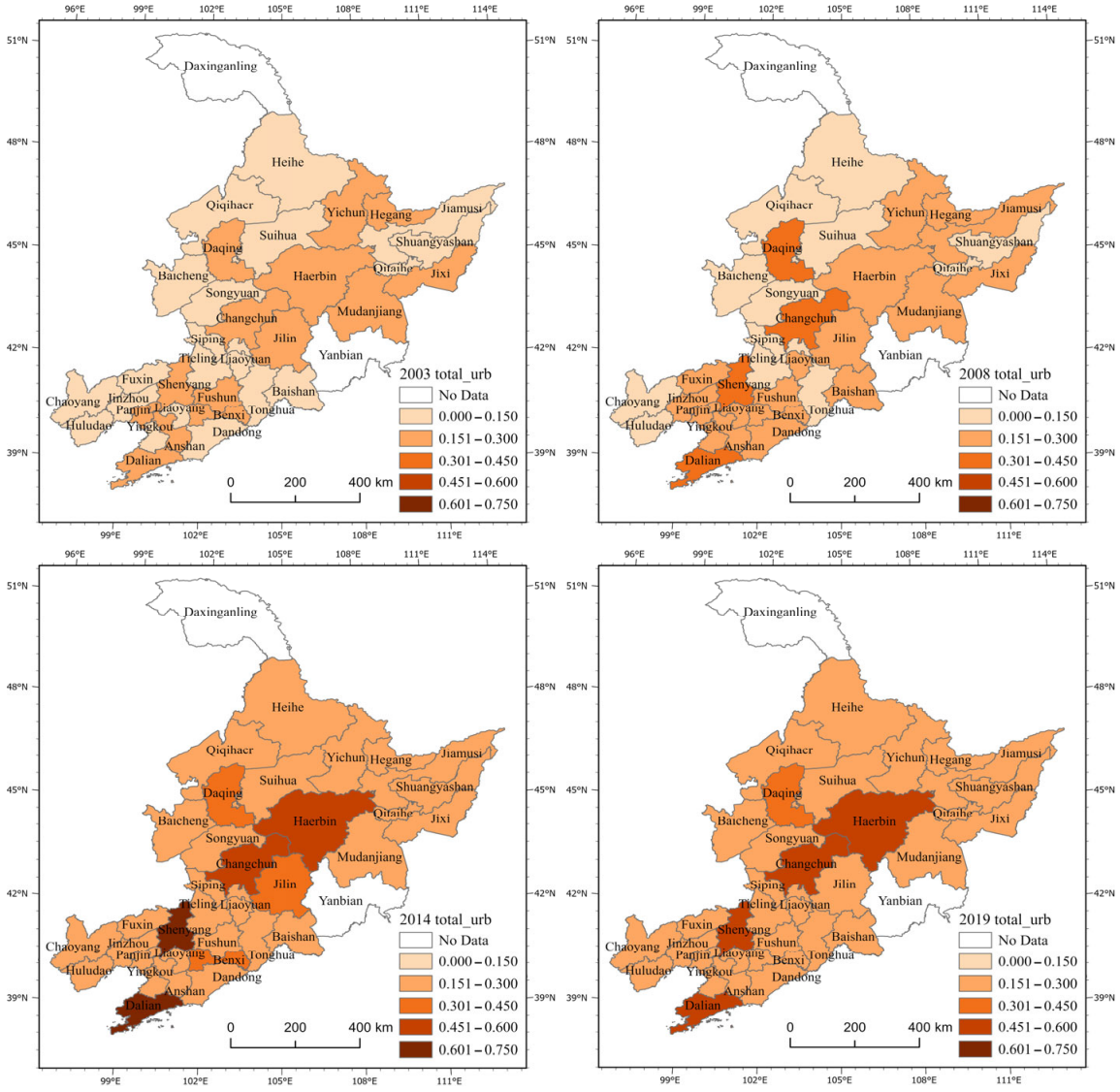

Figure 6. Spatial pattern of urbanization level (*total_urb*) in 2003, 2008, 2014, and 2019 in Northeast China.

Meanwhile, the *dem_urb* in Northeast China is best, followed by the *eco_urb*, the *soc_urb*, and the *spa_urb*, which are closely related to a strong education strength, relatively high urban population, weak economic growth, social security shortages, and unreasonable urban spatial distribution in Northeast China. In addition, although the educational strength in Northeast China is strong, its contribution to the labor force human capital is the smallest in China, and the positive effect of education plus urbanization on labor force quality in Northeast China is almost fully offset by population aging [70], i.e., human capital does not play a great economic utility in Northeast China. Moreover, Northeast China is failing to retain talents from within and outside the region with economic recession, which leads to a great loss of talents; it has become one of the key factors restricting the revitalization of Northeast China. Even for Dongguan City, located in the Pearl River Delta—one of the most representative areas of rapid urbanization in China—the disappearance of population dividends has accelerated its urban shrinkage [71]. Therefore, the new urbanization development in Northeast China with severe shrinkage is an arduous and complex task, and Northeast China should take a development path different from the current trend of China's overall urbanization growth.

4.3. Empirical Relationship between Urban Comprehensive Carrying Capacity and Urbanization

This study employs a pooled ordinary least squares (OLS) model and random-effect (RE) and fixed-effect (FE) models with the cluster-robust standard errors to explore the relationship between urban comprehensive carrying capacity and comprehensive urbanization level in Northeast China. The estimated results are shown in columns (1)–(3) in Table 5, and they show that urbanization has significantly positive effects on urban comprehensive carrying capacity at the 1% level, promoting urban comprehensive carrying capacity development by 0.611%, 0.692%, and 0.663% with 1% urbanization improvement, respectively; while its quadratic term (*total_urb*2) has significant negative effects on the urban comprehensive carrying capacity for the three kinds regression models, indicating that there is a significant inverted U-shaped curve relationship between urban comprehensive carrying capacity and urbanization in Northeast China. In addition, we investigate the effects of urbanization on urban comprehensive carrying capacity in the nonshrinking and shrinking cities in Northeast China with the FE regression model. Columns (4) and (5) in Table 5 show that urbanization has significantly positive effects on the urban comprehensive carrying capacity of the shrinking cities in Northeast China at the 1% level, but does not have significantly positive effects on the urban comprehensive carrying capacity of the nonshrinking cities at the 1% level. Meanwhile, there is a significant inverted U-shaped curve relationship between urban comprehensive carrying capacity and urbanization in the shrinking cities in Northeast China, but no significant inverted U-shaped curve relationship in the shrinking cities, indicating that the new urbanization development in the shrinking cities would play a more significant role in improving local carrying capacity.

Table 5. Benchmark regression analysis of the relationship of urban comprehensive carrying capacity with urbanization in Northeast China.

Variables	**(1)** ***total_ucc***	**(2)** ***total_ucc***	**(3)** ***total_ucc***	**(4)** ***total_ucc***	**(5)** ***total_ucc***
	Pooled OLS	RE	FE	Nonshrinking	Shrinking
total_urb	0.611 ***	0.692 ***	0.663 ***	0.189	0.732 ***
	(0.121)	(0.107)	(0.134)	(0.199)	(0.147)
*total_urb*2	−0.283 **	−0.431 ***	−0.416 ***	0.0381	−0.406 **
	(0.126)	(0.0966)	(0.122)	(0.190)	(0.148)
lngdp_per	0.0164 ***	0.0124 **	0.0133 **	0.0234 **	0.0105
	(0.00579)	(0.00504)	(0.00573)	(0.00854)	(0.00648)
lnthir_indus	0.0245 ***	0.0321 ***	0.0340 ***	0.0693 ***	0.0275 ***
	(0.00858)	(0.00655)	(0.00744)	(0.0130)	(0.00897)
lnfdi_gdp	0.0143 ***	0.0122 ***	0.0118 ***	0.0174 ***	0.0102 ***
	(0.00327)	(0.00235)	(0.00245)	(0.00227)	(0.00315)
lnuti_solid_waste	0.00785 *	0.00727 ***	0.00717 ***	−0.00388	0.00764 ***
	(0.00408)	(0.00224)	(0.00221)	(0.00577)	(0.00238)
Constant	−0.138 **	−0.129 **	−0.139 **	−0.236 **	−0.103
	(0.0566)	(0.0581)	(0.0642)	(0.0727)	(0.0750)
Observations	578	578	578	102	476
R-squared	0.864		0.744	0.878	0.722
Number of city		34	34	6	28

Notes: Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; brackets for the standard errors. Pooled OLS = pooled ordinary least squares (OLS) model; RE = random-effect model; FE = fixed-effect (FE) model; *total_ucc* = urban comprehensive carrying capacity; *total_urb* = urbanization level; *total_urb*2 = *total_urb*×*total_urb*; *lngdp_per* = logarithm of the per-capita gross domestic product (GDP); *lnthir_indus* = logarithm of the proportion of tertiary industry in GDP; *lnfdi_gdp* = logarithm of the proportion of foreign direct investment (FDI) out of GDP; *lnuti_solid_waste* = logarithm of the general solid waste treatment rate.

In addition, we also analyze the heterogeneity of the empirical relationship between the three components of urban comprehensive carrying capacity, namely, the *recc*, the *ecc*, and the *scc*, and urbanization with the FE robust model. The results are shown in columns (1)–(3) of Table 6, showing that urbanization has significantly positive effects on the *recc* and the *scc* in Northeast China at the 1% level, and there is an inverted U-

shaped curve relationship between them at the 1% level. However, it is different for the *ecc* where urbanization has significantly positive effects on it at the level of 10%, and there is also no significant curve relationship between urbanization and the *ecc*. Moreover, this study explores the heterogeneity of the relationship between urbanization and urban comprehensive carrying capacity in Liaoning Province, Jilin Province, and Heilongjiang Province. Columns (4)–(6) in Table 6 show that urbanization in Liaoning and Heilongjiang Provinces has significantly positive effects on urban comprehensive carrying capacity at the 1% and 10% levels, respectively, while urbanization in Jilin Province has not significantly improved its urban comprehensive carrying capacity. Meanwhile, there is a significant inverted U-shaped curve relationship between urbanization and urban comprehensive carrying capacity in Liaoning Province, but there is no significant inverted U-shaped curve relationship in Jilin and Heilongjiang Provinces. Therefore, it can be seen that the urbanization development of Liaoning Province plays a leading and decisive role in the improvement in urban comprehensive carrying capacity in Northeast China. It is verified from the side that Liaoning Province has always played a leading and core role in the improvement in the carrying capacity of the northeast region.

Table 6. Heterogeneity regression analysis of the relationship between urban comprehensive carrying capacity and urbanization based on its three components and in the three provinces of Northeast China.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	recc	*ecc*	*scc*	*total_ucc*	*total_ucc*	*total_ucc*
				Liaoning	Jilin	Heilongjiang
total_urb	0.280 ***	0.151 *	0.231 ***	0.992 ***	0.666	0.336 *
	(0.0990)	(0.0826)	(0.0336)	(0.152)	(0.486)	(0.180)
*total_urb*2	−0.333 ***	0.0441	−0.127 ***	−0.700 ***	−0.442	−0.0936
	(0.107)	(0.0865)	(0.0342)	(0.139)	(0.495)	(0.210)
lngdp_per	0.00769 **	0.00693 **	−0.00138	0.000245	0.00750	0.0294 ***
	(0.00347)	(0.00327)	(0.00149)	(0.00564)	(0.0172)	(0.00665)
lnthir_indus	0.0139 **	0.00799	0.0121 ***	0.0399 ***	0.0334	0.0344 ***
	(0.00542)	(0.00475)	(0.00222)	(0.00689)	(0.0224)	(0.00666)
lnfdi_gdp	−0.00446 **	0.0178 ***	−0.00152 **	0.00845 ***	0.0196 **	0.0150 ***
	(0.00176)	(0.00176)	(0.000677)	(0.00252)	(0.00653)	(0.00239)
lnuti_solid_waste	0.00683 ***	−0.000277	0.000592	0.00566 ***	0.00101	0.0158 **
	(0.00180)	(0.00141)	(0.000754)	(0.00100)	(0.00967)	(0.00586)
Constant	−0.0763 *	−0.0611 *	−0.000806	−0.0636	−0.0706	−0.291 ***
	(0.0396)	(0.0323)	(0.0151)	(0.0535)	(0.167)	(0.0664)
Observations	578	578	578	238	136	204
R-squared	0.425	0.619	0.754	0.819	0.751	0.705
Number of city	34	34	34	14	8	12

Notes: Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; brackets for the standard errors; *recc* = resource and environmental carrying capacity; *ecc* = economic carrying capacity; *scc* = social carrying capacity; *total_ucc* = urban comprehensive carrying capacity; *total_urb* = urbanization level; *total_urb*2 = *total_urb*×*total_urb*; *lngdp_per* = logarithm of the per-capita gross domestic product (GDP); *lnthir_indus* = logarithm of the proportion of tertiary industry in GDP; *lnfdi_gdp* = logarithm of the proportion of foreign direct investment (FDI) out of GDP; *lnuti_solid_waste* = logarithm of the general solid waste treatment rate.

Moreover, this study also discusses the interaction mechanism of urbanization on the urban comprehensive carrying capacity, and the results are shown in Table 7. It shows that *dem_urb* and *eco_urb* have significantly promoted the improvement in urban comprehensive carrying capacity in Northeast China, and once the quality of urbanization crosses a certain inflection point, *soc_urb* will play a positive role in promoting the development of the region's urban comprehensive carrying capacity. In the near future, the moderate increase in population and the reduction in population outflow, especially the improvement in population quality, are important factors for improving the sustainable development of the cities in Northeast China. In addition, maintaining high-quality economic development is also the main way to promote the improvement in carrying capacity.

Table 7. Mechanism analysis of the relationship between urban comprehensive carrying capacity and urbanization in Northeast China.

Variables	(1) *total_ucc*	(2) *total_ucc*	(3) *total_ucc*	(4) *total_ucc*
dem_urb	0.904 **			
	(0.443)			
*dem_urb*2	1.036			
	(1.545)			
lngdp_per	0.0329 ***	0.0328 ***	0.0456 ***	0.0356 ***
	(0.00373)	(0.00470)	(0.00332)	(0.00373)
lnthir_indus	0.0356 ***	0.0544 ***	0.0534***	0.0338 ***
	(0.00780)	(0.00776)	(0.00900)	(0.00703)
lnfdi_gdp	0.0135 ***	0.0111 ***	0.0110 ***	0.0144 ***
	(0.00252)	(0.00251)	(0.00288)	(0.00243)
lnuti_solid_waste	0.00693 ***	0.00621 **	0.00682 **	0.00919 ***
	(0.00236)	(0.00267)	(0.00302)	(0.00297)
eco_urb		0.295 **		
		(0.115)		
eco_urb2		−0.122		
		(0.207)		
spa_urb			−1.833	
			(1.598)	
*spa_urb*2			25.75	
			(19.33)	
soc_urb				0.234
				(0.357)
*soc_urb*2				4.672 **
				(2.029)
Constant	−0.306 ***	−0.303 ***	−0.385 ***	−0.281 ***
	(0.0427)	(0.0609)	(0.0626)	(0.0517)
Observations	578	578	578	578
R-squared	0.713	0.700	0.662	0.712
Number of city	34	34	34	34

Notes: Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$; brackets for the standard errors. *total_ucc* = urban comprehensive carrying capacity; *dem_urb* = demographic urbanization level; *dem_urb*2 = *dem_urb*×*dem_urb*; *lngdp_per* = logarithm of the per-capita gross domestic product (GDP); *lnthir_indus* = logarithm of the proportion of tertiary industry in GDP; *lnfdi_gdp* = logarithm of the proportion of foreign direct investment (FDI) out of GDP; *lnuti_solid_waste* = logarithm of the general solid waste treatment rate; *eco_urb* = economic urbanization level; *eco_urb*2 = *eco_urb*×*eco_urb*; *soc_urb* = social urbanization level; *soc_urb*2 = *soc_urb*×*soc_urb*; *spa_urb* = spatial urbanization level; *spa_urb*2 = *spa_urb*×*spa_urb*.

According to the results of Table 7, this paper further analyzes the effects of the constituent variables of demographic urbanization, economic urbanization, and social urbanization on the urban comprehensive carrying capacity of the shrinking cities in Northeast China (Table 8). The results show that the variables of *urban_rate*, *colle_stud*, *fixed_inves*, *retail_sales*, and *inter_user* (showed in Table 2) significantly promote the improvement in the urban comprehensive carrying capacity of the shrining cities in Northeast China. Meanwhile, regarding which variable ultimately determines the inverse U-shaped curve relationship between the urban comprehensive carrying capacity and urbanization in the shrinking cities, the analysis results indicate that the three variables of *fixed_inves*, *retail_sales*, and *inter_user* (shown in Table 2) play significantly important roles in it, and the variables of *indus_value* and *pub_book* (showed in Table 2) adversely play significant roles in forming a U-shaped curve relationship with the urban comprehensive carrying capacity in the shrinking cities. The definitions of urban shrinkage introduced in the academic literature and the Shrinking Cities International Research Network generally focus on population loss and economic decline [72]. As the most important old industrial base, economic recession, population loss, and the lack of social services are serious challenges facing Northeast China. Hence, the quality of demographic, economic, and social urbanization in the shrinking cities will play different roles in the development of urban carrying capacity.

Table 8. The effects of the component variables of urbanization level on urban comprehensive carrying capacity in Northeast China.

Demographic Urbanization	***total_ucc***	**Economic Urbanization**	***total_ucc***	**Social Urbanization**	***total_ucc***
urba_rate	2.690 **	*gdp_per*	0.187	*medi_staff*	−0.370
	(1.095)		(0.856)		(1.013)
*urba_rate*2	−28.95	*gdp_per*2	5.763	*medi_staff*2	58.72
	(17.59)		(6.494)		(52.17)
pop_dens	7.031	*fixed_inves*	1.020 **	*pub_book*	−0.471
	(12.33)		(0.442)		(0.533)
*pop_dens*2	107.2	*fixed_inves*2	−11.33 **	*pub_book*2	24.05 **
	(403.6)		(4.538)		(9.549)
terti_emp	−0.221	*indus_value*	−0.964 *	*hosp_bed*	−0.0780
	(0.791)		(0.510)		(3.290)
*terti_emp*2	14.06	*indus_value*2	21.79 ***	*hosp_bed*2	53.40
	(21.58)		(7.692)		(128.1)
colle_stud	1.114 **	*profit*	−0.120	*pub_trans*	−0.250
	(0.415)		(0.261)		(0.276)
*colle_stud*2	−5.198	*profit*2	−1.706	*pub_trans*2	7.038
	(8.754)		(4.022)		(4.516)
Constant	−0.0732	*retail_sales*	1.808 **	*inter_user*	2.650 ***
	(0.143)		(0.802)		(0.547)
Observations	476	*retail_sales*2	−12.31 *	*inter_user*2	−41.26 ***
R-squared	0.786		(6.375)	Number of city	28

Notes: Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; brackets for the standard errors. The variables without the number 2 in the first, third, and fifth columns are the same as those in Table 2; the variables with the number 2 in the first, third, and fifth columns are the square of the same variables without the number 2.

Finally, in order to further verify the robustness of the results, we conduct the following robustness tests: (1) The time sample is changed from the year of 2003–2019 to the year of 2008–2019 (column (1) in Table 9). (2) Since Liaoning Province plays an important role in the empirical analysis of the relationship between urbanization and urban comprehensive carrying capacity in Northeast China, this study narrows down three important cities in Liaoning Province, namely, Shenyang (the provincial capital and sub-provincial city), Dalian (sub-provincial city), and Anshan (one of the most important steel cities in China), retaining 31 prefecture-level cities (column (2) in Table 9). (3) As one of the most famous old industrial bases in China, there is a great degree consistency between urbanization and industrialization with an obvious positive correlation in Northeast China. Therefore, this study uses the ratio of secondary industry to GDP to replace the urbanization quality index, which represents the degree of urbanization development in Northeast China (column (3) in Table 9). (4) Since this study uses the cities in Northeast China as the cross-section, which is larger than the number of time series, the Panel-Corrected Standard Errors (PCSEs) are used for re-examination of the empirical results (column (4) in Table 9). The results show that the urbanization coefficient in Table 8 is still significantly positive, and its quadratic term is significantly negative, which is basically consistent with the previous empirical results.

Table 9. Robustness tests of the relationship between urban comprehensive carrying capacity and urbanization in Northeast China.

Variables	**(1)** ***total_ucc***	**(2)** ***total_ucc***	**(3)** ***total_ucc***	**(4)** ***total_ucc***
total_urb	0.721 ***	0.758 ***		0.611 ***
	(0.0949)	(0.161)		(0.0559)
total_urb2	−0.418 ***	−0.569 ***		−0.283 ***
	(0.0825)	(0.170)		(0.0740)

Table 9. *Cont.*

Variables	(1) *total_ucc*	(2) *total_ucc*	(3) *total_ucc*	(4) *total_ucc*
lngdp_per	0.0136 **	0.0112 *	0.0487 ***	0.0164 ***
	(0.00628)	(0.00620)	(0.00339)	(0.00437)
lnthir_indus	0.0394 ***	0.0330 ***	0.00674	0.0245 ***
	(0.00577)	(0.00764)	(0.0177)	(0.00609)
lnfdi_gdp	0.0113 ***	0.0127 ***	0.0121 ***	0.0143 ***
	(0.00302)	(0.00269)	(0.00316)	(0.00274)
lnuti_solid_waste	0.00790 ***	0.00682 ***	0.00828 ***	0.00785 ***
	(0.00268)	(0.00222)	(0.00277)	(0.00210)
lnsec_indus			0.252 ***	
			(0.0863)	
lnsec_indus2			−0.0420 ***	
			(0.0135)	
Constant	−0.179 **	−0.127 *	−0.638 ***	−0.138 **
	(0.0683)	(0.0667)	(0.119)	(0.0563)
Observations	408	527	578	578
R-squared	0.662	0.726	0.677	0.864
Number of city_code	34	31	34	34

Notes: Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; brackets for the standard errors. *total_ucc* = urban comprehensive carrying capacity; *total_urb* = urbanization level; *total_urb*2 = *total_urb*×*total_urb*; *lngdp_per* = logarithm of the per-capita gross domestic product (GDP); *lnthir_indus* = logarithm of the proportion of tertiary industry in GDP; *lnfdi_gdp* = logarithm of the proportion of foreign direct investment (FDI) out of GDP; *lnuti_solid_waste* = logarithm of the general solid waste treatment rate; *lnsec_indus* = logarithm of the secondary industry GDP; *lnsec_indus*2 = *lnsec_indus*×*lnsec_indus*.

5. Conclusions and Suggestions

The local urban shrinkage represented by Northeast China has begun to take shape in China. The traditional urban cognition and planning paradigm based on 'growth scenario simulation' needs to be transformed. Exploring sustainable urban development under the context of slow growth or reverse growth is not only a major challenge for sustainable urban development in the future but also a new proposition that urgently needs to be focused on and studied. This study develops index systems for the evaluation of the urban comprehensive carrying capacity and the comprehensive urbanization level from 2003 to 2019 in Northeast China, which is now a lagging region in China with serious urban shrinkage. The two index systems are used to explore the relationship between the urban comprehensive carrying capacity and the comprehensive urbanization level in the context of the recession of Northeast China with panel data econometric models. Some important findings are highlighted as follows.

First, the urban comprehensive carrying capacity and comprehensive urbanization quality have been improved, the performance of the resources and environmental carrying capacity in Northeast China is relatively good, while the social carrying capacity is the weakest aspect. Meanwhile, the cities with relatively high urban comprehensive carrying capacity levels are gathered along the Harbin–Dalian High-speed Railway Line, which is consistent with the trend of the comprehensive urbanization level distribution. Second, the ordinary panel data model regression shows that urbanization has significantly positive effects on urban comprehensive carrying capacity, and there is a significant inverted U-shaped curve relationship between them in Northeast China. Moreover, urbanization has a significantly positive effect on urban comprehensive carrying capacity in the shrinking cities, and the economic urbanization variables of the fixed-asset investment, the total retail sales of social consumer goods, and the social urbanization variable of internet users play significantly important roles in forming the inverted U-shaped curve relationship with the urban comprehensive carrying capacity of the shrinking cities in Northeast China.

The ultimate goal of this study is to improve the urban comprehensive carrying capacity of Northeast China. The results of this study show that the social carrying capacity is the field in which Northeast China needs to take the lead and focus on improvement,

where employment, pensions, medical treatment, and education are the top priorities. The equalization of basic public services is the key index to measure new types of urbanization. The second is the economic carrying capacity; the economic downturn is the greatest challenge facing the region, and it is also an important reason why its social carrying capacity cannot be effectively improved. Therefore, a vigorously developing economy is still the only way to escape recession. Innovation is the fundamental driving force of economic growth. Therefore, to escape the mire of the economic recession, the 'best' development path for northeast China may be to develop innovation-driven industries and economic transformation development based on complying with the tendency toward urban shrinkage [37,73]. Intelligent manufacturing and digital empowerment have become practical choices for industrial innovation and upgrading in Northeast China [74–76].

Currently, China is beginning to enter the fifth economic long wave represented by information technology, while Northeast China is still in the fourth economic long wave based on manufacturing, oil, steel, etc. The advantages of industrial development will continue to be lost, and the region will experience long-term economic shrinkage in the future [31]. Therefore, the top priority in Northeast China is to adjust the economic structure and industrial structure through technological and institutional innovation, to upgrade and transform advantageous industries based on information technology, and to cultivate and expand strategic emerging industries. Northeast China should focus on eliminating path dependence and shift from investment-driven to innovation-driven to achieve all-around revitalization.

Importantly, as a typical region affected seriously by urban shrinkage, in addition to the abovementioned efforts to develop the economy and to enhance economic carrying capacity, Northeast China should focus on moderately increasing the natural birth rate by abolishing family planning policies; alleviating talent outflow, especially creating a mechanism to retain and attract talents; improving population quality; providing a high-quality human resource carrying capacity for regional sustainable development; and improving urban resilience. Northeast China should pay more attention to the leading role of the four core cities of Shenyang, Dalian, Changchun, and Harbin and to improve their positive spatial spillover effects in new urbanization development.

Finally, the quality of water resources, air, and soil and the ability to resist natural disasters are important contents of the urban comprehensive carrying capacity. However, due to the limitation of data acquisition, these factors are not reflected in the index system of the urban comprehensive carrying capacity. In addition, urban and rural residents enjoying equal public services is the main goal of new urbanization development, but due to data limitations, these contents cannot be fully displayed in the comprehensive urbanization evaluation system. Therefore, in the follow-up research, new data such as point of interest data will be used to conduct an integrated and systematic analysis of the key factors affecting urban carrying capacity and urbanization quality, to more accurately evaluate the sustainable urban development in Northeast China.

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