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Spatiotemporal Evolution of Urban Shrinkage and Its Impact on Urban Resilience in Three Provinces of Northeast China

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Abstract: Currently, Chinese cities are experiencing both overall growth and localized shrinkage. Therefore, it becomes crucial to quantify urban shrinkage and explore the transformation and sustainable development of shrinking cities from the perspective of urban resilience. This study focuses on the three provinces of Northeast China, which are representative areas of urban shrinkage, as its research subjects. Employing the analytic hierarchy process, a comprehensive evaluation system for urban shrinkage is constructed based on three dimensions: population, economy, and space. Furthermore, urban resilience is scientifically measured from four aspects: economy, society, ecology, and infrastructure. The study analyzes the spatiotemporal evolution characteristics of urban shrinkage and urban resilience in the three northeastern provinces from 2012 to 2018. It also examines the impact of urban shrinkage on urban resilience through regression analysis and mediation models. The results indicate the following: (1) Half of the cities in the three northeastern provinces experienced shrinkage, although the extent of shrinkage decreased with the implementation of the Northeast China revitalization strategy. Population-related shrinkage was the most extensive and continued to expand, while economy-related shrinkage was the most severe, and space-related shrinkage was the least severe. (2) The resilience of shrinking cities was lower than the average level. Population-shrinking cities and economy-shrinking cities exhibited low levels of economic resilience, and the gap between them continued to widen. Space-shrinking cities generally had low infrastructure resilience. (3) The urban shrinkage index had a significant positive impact on the urban resilience index, mediated through intermediary variables, such as innovation capability and cultural development. Notably, both the direct and indirect effects of innovation capability were the greatest. Population-related shrinkage had the largest impact on urban resilience, while more intermediary variables of economy-related shrinkage passed the significance test.

Keywords: urban shrinkage; urban resilience; mediating effect; smart shrinkage; three provinces of Northeast China

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1. Introduction

Since the mid-20th century, the phenomenon of urban shrinkage, which runs counter to urban growth, emerged in developed Western countries and gradually affected developing nations undergoing rapid urbanization [1]. In the wake of China's reform and opening-up policies, urbanization experienced rapid advancement and reached a stage where the urban population takes the lead. However, amidst the backdrop of urban expansion and continuous population concentration in cities, localized urban shrinkage became increasingly evident in China [2]. This phenomenon is not confined to resource-dependent cities with relatively slow development [3], but also occurs in economically advanced regions such as the Beijing–Tianjin–Hebei and Yangtze River Delta areas [4]. Presently, the coexistence of urban shrinkage and rapid urbanization [5], alongside overall urban growth with localized shrinkage, represents an undeniable reality in China. Urban shrinkage became a significant

challenge that must be addressed in China's future new-type urbanization process [6,7]. Both domestic and international scholars extensively and profoundly discussed the theoretical and empirical aspects of urban shrinkage, including its conceptualization [8,9], spatiotemporal variations [10,11], typology [12], driving mechanisms [5], and coping strategies [13]. Initially, urban shrinkage primarily referred to the phenomenon of population decline observed in cities in Germany, the United States, and other countries during the mid-20th century [14,15]. Consequently, early measures of urban shrinkage predominantly relied on population changes as the benchmark [16]. However, as scholars delved into the diverse characteristics of urban shrinkage, a comprehensive understanding of the concept emerged, considering multiple dimensions, such as population, economy, society, and space [17]. Regarding typology, academia often categorizes urban shrinkage based on the spatial distribution of population. The most common types are the "perforated" city, exemplified by industrial cities in Europe [18], and the "donut" city, represented by the Rust Belt region in the northeastern United States [19]. Other types include the "reverse sector" and "star-shaped" cities. Since the 21st century, scholars shifted their focus towards strategies and regulatory measures to address urban shrinkage, resulting in two primary response policies: "resistance" and "adaptation." The former advocates measures to revitalize urban areas, while the latter views shrinkage as a normal stage of urban development and promotes active adaptation through smart shrinkage strategies. Currently, the latter approach gained widespread recognition as an important means of addressing shrinkage [20]. In summary, research on urban shrinkage demonstrates characteristics such as multidimensional indicators and diversified data sources. However, previous studies predominantly focused on measuring urban shrinkage using a single population indicator, failing to capture the comprehensive nature of the concept. Moreover, existing research tends to solely examine the phenomenon of urban shrinkage itself, neglecting the analysis of variations and dynamic changes during the shrinkage process [21], as well as the study of its impacts. Nonetheless, these issues bear significant implications for the transformation and sustainable development of shrinking cities.

In recent years, urban resilience gained significant attention in response to a series of crises triggered by globalization, urbanization, and other factors. The term "resilience" originated from the fields of physics, engineering, and ecology [22,23], referring to the restoration of something to its original state. In the 1970s, ecologist C.S. Holling introduced the concept of ecological resilience [24], which pertains to the ability of an ecosystem to withstand and recover from adverse environmental conditions. Additionally, evolutionary resilience was proposed, emphasizing a system's ability to achieve sustainable development through structural modifications and pathway alterations [25]. From a geographical perspective, resilience is defined as the ability of regional (urban) systems to respond to external pressures and disturbances by changing, adapting, and transforming [26]. The notion of "resilient cities" was initially introduced by the Local Governments for Sustainability (ICLEI) in 2002, leading to the integration of resilience into urban research. However, there is no universally agreed-upon definition for urban resilience within the conceptual framework. Pickett et al. describe urban resilience as the system's ability to adapt to changes [27], while Zhao et al. propose that urban resilience involves adaptation, learning, and recovery when human and environmental systems face challenges [28]. Ning et al. define urban resilience as the capacity of urban systems to adapt, maintain, and recover in the face of disturbances [29]. Previous studies employed comprehensive indicators to measure urban resilience. Hudec et al. analyzed Slovakia's urban resilience during the financial crisis, utilizing 12 indicators across three dimensions: economic capacity, sociodemographic capacity, and community connectivity capacity [30]. Bai et al. developed a comprehensive measurement system for urban resilience in China, comprising 28 indicators encompassing the economy, society, ecology, and infrastructure [31]. Factors influencing urban resilience include natural disasters [32], socio-cultural environments [33], and infrastructure development [34]. Resilient urban planning is a practical manifestation of significance in related research, and scholars actively explored the constituent elements, theoretical designs, and

simulation of resilient cities [35]. However, limited research was conducted on changes in urban resilience under urban crises, often neglecting the relationship between urban resilience and urban shrinkage. In general, urban resilience emphasizes the urban system's ability to achieve sustainable development through internal adjustments following disturbances, effectively representing the city's capacity to withstand risks and recover from crises. In contrast, urban shrinkage generally implies a relative weakening or absolute degradation of urban development potential, inevitably resulting in negative impacts on various aspects of urban development [5,36]. Therefore, urban resilience provides an explanation for the dynamic changes occurring during the process of urban shrinkage and the ability to return to the original condition. The exploration of urban resilience and development pathways amidst the crisis of urban shrinkage is vital for shrinking cities to cope with crises and achieve high-quality development.

The three provinces in Northeast China, historically known as the "cradle" of industrial development soon after the founding of the People's Republic of China, currently face the challenge of population outflow and a low GDP growth rate. This situation arises from the depletion of natural resources and the presence of an irrational industrial structure. Moreover, the economic decline and population outflow in these northeastern provinces made it difficult to enhance urban resilience, thereby becoming significant factors constraining their sustainable development. To revitalize Northeast China in the new era, it is essential to quantify the phenomenon of urban shrinkage and explore sustainable development approaches for shrinking cities in these provinces. Urban shrinkage poses a considerable challenge for the northeastern provinces. Understanding the spatiotemporal patterns of urban shrinkage in this region and exploring the mechanisms through which it affects urban resilience can pave the way for enhancing resilience. This, in turn, will strengthen the region's ability to withstand risks and foster sustainable development, thereby contributing to the high-quality and continuous progress of the northeastern provinces. Hence, this study aimed to develop a comprehensive evaluation system that captures the phenomenon of urban shrinkage by considering population, economy, and space. Additionally, urban resilience was measured from four perspectives: economy, society, ecology, and infrastructure. In light of this, the study examined the impact of urban shrinkage and its various dimensions on urban resilience. Furthermore, it explored the development pathway of urban resilience within the three provinces in the context of shrinkage. The findings of this study can serve as a reference for urbanization and the pursuit of high-quality development in Northeast China.

2. Materials and Methods

2.1. Study Area

The three provinces of Northeast China, namely Heilongjiang, Jilin, and Liaoning (Figure 1), encompass a total area of 787,300 km^2. These provinces witnessed significant population decline due to the "Northeast Phenomenon" and the "New Northeast Phenomenon." According to the data from the Seventh National Population Census, the population in these provinces decreased by 10.9982 million in 2020 compared to 2010. Specifically, Liaoning, Jilin, and Heilongjiang experienced a population decrease of 1.1549 million, 3.3794 million, and 6.4639 million, respectively. Consequently, the northeastern provinces became a prime example of urban shrinkage in China. Additionally, being the largest heavy industrial base in the country, the northeastern provinces are home to a significant number of old industrial cities and resource-dependent cities. These cities lack the intrinsic driving force for economic development, leading to low urban resilience. In summary, the northeastern provinces exhibit distinctive characteristics of urban shrinkage and possess low urban resilience, which can be explored to provide valuable insights into the relationship between urban shrinkage and urban resilience. The three provinces consist of 34 prefecture-level administrative divisions, with 14 falling under Liaoning, 9 under Jilin, and 13 under Heilongjiang. Considering the limited urban management functions in regional-level administrative units such as the Greater Khingan Range and Yanbian

Korean Autonomous Prefecture, this study excludes them from the research scope. Instead, it focuses on the 34 prefecture-level administrative divisions as the research subjects. In light of the features of cities concentrated with population and economic activities, China's administrative division system, and the availability of data, the municipal districts of prefecture-level cities were employed as the uniform scale in this study.

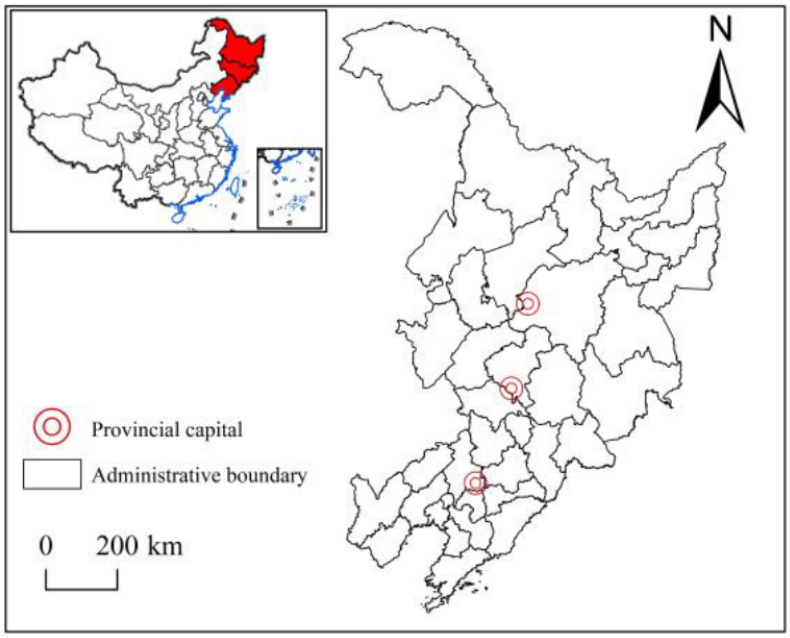

Figure 1. Administrative division of the three northeastern provinces.

2.2. The Comprehensive Evaluation System for Urban Shrinkage and Urban Resilience

2.2.1. Urban Shrinkage

In the past, population change served as a primary criterion for defining urban shrinkage. However, as the understanding of urban shrinkage evolved, population change alone came to represent only a narrow aspect of this phenomenon. To comprehensively discuss urban shrinkage, it is necessary to consider population, economy, society, and space. This study posits that urban shrinkage is a natural phase in urban development characterized by population and job losses, leading to declining GDPs, fiscal revenues, and spatial deterioration. Addressing the extent of urban shrinkage requires adaptation as a key approach. Building upon this perspective, we developed a comprehensive evaluation system for urban shrinkage in the three provinces of Northeast China. This system incorporates six indicators related to population, economy, and space, namely permanent population, number of employees, GDP, fiscal revenue, built-up area, and night-time light index of urban areas (Table 1). The permanent population in urban areas reflects the actual number of residents, while the number of employees indicates labor force employment. In terms of the economic dimension, the GDP of urban areas serves as an indicator of economic development, while fiscal revenue signifies economic benefits and government financial standing, both crucial measures of urban economic strength. Regarding spatial aspects, the built-up area represents an important indicator of urban development, while the night-time light index offers insights into a city's vibrancy.

2.2.2. Urban Resilience

A city's economy, society, and ecology are its fundamental components [37]. Among these, infrastructure plays a vital role in guaranteeing its survival and fostering development. Therefore, we utilized a set of 24 indicators encompassing these aspects to construct a comprehensive evaluation system for urban resilience in the northeastern provinces of China (Table 2).

Table 1. The comprehensive evaluation system for urban shrinkage.

Target Layer	Criterion Layer	Weight	Indicator Layer	Weight
Urban shrinkage	Population	0.5	Permanent population	0.572
			Number of employees	0.428
	Economy	0.3	GDP	0.525
			Fiscal revenue	0.475
	Space	0.2	Built-up area	0.462
			Night-time light index	0.538

Table 2. The comprehensive evaluation system for urban resilience.

Target Layer	Criterion Layer	Indicator Layer	Weight
Urban resilience	Economic resilience	Percentage of secondary and tertiary industries (%)	0.0513
		Number of enterprises above designated size	0.0363
		Balance of residents' savings (RMB 10,000 yuan)	0.0467
		Actual utilization of foreign capital (10,000 USD)	0.0339
		Percentage of science and technology expenditure in GDP (%)	0.0545
		Total retail sales of social consumer goods per capita	0.0377
	Social resilience	Natural population growth rate (%)	0.0423
		Number of college students per 10,000 people	0.0366
		Coverage of medical insurance (%)	0.0271
		Average wage of employees (RMB yuan)	0.0399
		Registered unemployed population in urban areas	0.0462
		Social dependency ratio (%)	0.0408
	Ecological resilience	Rate of green coverage (%)	0.0548
		Area of gardens and green spaces (km^2)	0.0378
		Comprehensive utilization of industrial solid wastes (%)	0.043
		Centralized treatment of urban domestic sewage (%)	0.0437
		Harmless disposal of domestic wastes (%)	0.0395
		Discharge of industrial wastewater per RMB 10,000 yuan of GDP (ton)	0.0559
	Infrastructure resilience	Per capita road area (m^2 per capita)	0.0473
		Drainage pipeline density (km/km^2)	0.0568
		Number of buses (electric vehicles) per 10,000 people	0.0372
		Number of hospital beds per 10,000 people	0.0367
		Number of mobile phone owners	0.0272
		Number of Internet users	0.0268

The economic resilience of a city is largely assessed based on its capacity to maintain stability amidst uncertain economic conditions [38]. This serves as the foundation for evaluating other criteria. In Northeast China, the secondary industries play a significant role in economic development, while the tertiary industries serve as an important indicator of an advanced industrial structure. The proportion of secondary and tertiary industries reflects the diversity of urban economic development. The number of large-scale enterprises and the balance of residents' savings offer insights into the economic development level from the perspectives of businesses and individuals, respectively. The actual utilization of foreign capital and the percentage of science and technology expenditure in GDP demonstrate the city's export-oriented economy and its technological innovation capabilities. Generally, a higher per capita total retail sales of social consumer goods indicates a more developed economy, and it reflects the residents' confidence and capacity for consumption, thereby driving economic development.

Secondly, urban social resilience refers to a city's capacity to recover and thrive after experiencing a disturbance. Unlike economic resilience, social resilience places emphasis on long-term sustainability. The city's ability to withstand crises can be reflected by the population growth rate, as indicated by the natural population growth rate. The number of

college students per 10,000 people and the extent of medical insurance coverage demonstrate the city's ability to cope with risks during crises. The average wage of employees reflects the income level of residents, while the registered unemployed population in urban areas and the social dependency ratio indicate the job stability and pressure faced by the labor force, both of which are indicative of social stability.

Thirdly, urban ecological resilience pertains to a city's capacity to adapt to environmental changes resulting from crises [39]. The extent of green coverage and the size of gardens and green spaces serve as indicators of the city's ecological service function. The comprehensive utilization of industrial solid waste, centralized treatment of urban domestic sewage, and proper disposal of household waste demonstrate the city's ability to maintain an environmentally friendly environment. Moreover, the volume of industrial wastewater discharged per RMB 10,000 yuan of GDP provides insights into the environmental governance challenges faced by the city.

Lastly, urban infrastructure resilience encompasses the rescue and emergency response capabilities of a city's physical infrastructure during times of crisis [40]. The per capita road area, density of drainage pipelines, the quantity of buses (including electric vehicles) per 10,000 people, and the number of hospital beds per 10,000 people serve as indicators of the city's level of infrastructure facilities. Additionally, the number of mobile phone owners and Internet users can be utilized to assess the city's ability to communicate externally.

2.3. Theoretical Mechanisms of Urban Shrinkage's Impact on Urban Resilience

While urban shrinkage is acknowledged as an inherent phase in the process of urban development, it is undeniable that it poses negative implications for socioeconomic progress. This study delves into the underlying mechanisms by which urban shrinkage influences urban resilience, examining four mediating variables: innovation capability, cultural development, urbanization rate, and environmental quality.

Innovation capability: Firstly, urban shrinkage leads to a decline in population, which in turn weakens the available human capital within the city. Secondly, the population outflow during shrinkage predominantly comprises a young labor force and highly skilled individuals, which negatively impacts the vitality of urban innovation. Thirdly, urban shrinkage disrupts the clustering of innovation activities, hindering the creation of a conducive environment for innovation. Innovation acts as an inherent propeller for urban economic development and significantly contributes to enhancing urban resilience. Cities that embrace a culture of innovation are better equipped to recover swiftly from economic crises [41].

Cultural development: While previous studies primarily focused on cultural-oriented strategies to manage urban shrinkage, it is essential to acknowledge that urban shrinkage also has implications for cultural development. On one hand, population outflow results in a reduction in the workforce dedicated to cultural development, leading to the erosion of existing cultural forms and traditions. On the other hand, urban shrinkage negatively affects government finances, which hinders the promotion of cultural development. Culture plays a pivotal role in fostering urban resilience. A vibrant cultural and artistic scene is crucial for fostering social connections, building confidence, and ultimately enhancing urban resilience. Furthermore, cultural industries make significant contributions to urban economic development.

Urbanization rate: Urbanization entails the migration of individuals from rural to urban areas, while urban shrinkage represents a relative decline in the agglomeration capacity of developmental factors within the urban competitive network [42], primarily characterized by population and capital outflow. Thus, urban shrinkage may impede the progress of urbanization to some extent. Conversely, urbanization has a notable positive influence on urban resilience. During the urbanization process, the continuous concentration of population, capital, and other developmental factors, coupled with the expansion of urban areas, stimulates economic growth and prosperity, facilitates intercity communication and integration, and enhances the capacity to withstand external shocks.

Environmental quality: The relationship between urban shrinkage and environmental quality involves intricate interaction and feedback mechanisms [43]. Urban shrinkage exhibits both positive and negative influences on environmental quality. On one hand, the reduction in population and human activity can alleviate the ecological burden, consequently improving environmental quality. On the other hand, urban shrinkage negatively affects environmental quality by contributing to the deterioration of the living environment in shrinking cities. A favorable ecological environment, however, can attract talented individuals and businesses, thereby enhancing urban resilience.

2.4. Methods

2.4.1. Analytic Hierarchy Process

The analytic hierarchy process (AHP) was employed to assign weights to the criterion layer and indicator layer. In the evaluation system for urban shrinkage, the weight of the criterion layer was determined through the expert scoring method, while the weight for the urban shrinkage and urban resilience indicator layers was determined using the entropy method. The entropy method not only eliminates the inherent subjectivity and randomness in weighting, but also addresses the issue of information overlap among multiple indicators. Consequently, there is no need for repetitive calculation processes.

To calculate the comprehensive shrinkage index for urban shrinkage indicators in the three northeastern provinces, the standardized values of each indicator were multiplied by their respective weights and then summed. This process yields the population-related shrinkage index, economy-related shrinkage index, and space-related shrinkage index. These indices were further weighted and summed to obtain the comprehensive urban shrinkage index. The calculation equation is as follows:

$$US_c = \sum_{i=1}^{n} r_i W_i \quad (1)$$

In Equation (1), US_c represents the urban shrinkage criterion layer index in the three northeastern provinces, including the population-related, economy-related, and space-related shrinkage indices; r_i denotes the standardized value of the indicator; and W_i is the weight of the indicator.

$$US = \sum_{j=1}^{m} (US_c)_j W_j \quad (2)$$

In Equation (2), US represents the comprehensive urban shrinkage index in the three northeastern provinces; W_j is the weight of the criterion layer.

Similarly, the calculation process for the urban resilience index is identical. First, the standardized values of each resilience indicator were multiplied by their respective weights and then summed. This process yields the economic resilience index, social resilience index, ecological resilience index, and infrastructure resilience index. These indices were then weighted and summed to obtain the comprehensive urban resilience index.

2.4.2. Shrinkage Model

The shrinkage model was employed to assess the extent of urban shrinkage and determine whether a city is experiencing shrinkage. Specifically, population-related shrinkage can be quantified using the following equation.

The shrinkage model was used to determine whether and to what extent the city is shrinking. For example, population-related shrinkage can be calculated by the following equation:

$$S_{iP} = \frac{X_{iP}(2018) - X_{iP}(2012)}{X_{iP}(2012)} \quad (3)$$

In Equation (3), S_{iP} is the population-related shrinkage index of city i, and if it is less than 0, the city is experiencing population-related shrinkage; X_{iP} (2012) and X_{iP} (2018) are the permanent residents of city i in 2012 and 2018, respectively. The method of calculating population-related shrinkage applies to both economy-related shrinkage and space-related shrinkage. In accordance with the grading of the shrinkage index in existing research [44,45] and the actual

situation of the study area, the urban shrinkage in the three provinces of Northeast China was classified as severe shrinkage ($S < -0.2$), moderate shrinkage ($-0.2 \leq S < -0.1$), mild shrinkage ($-0.1 \leq S < -0.05$), and slight shrinkage ($-0.05 \leq S < 0$).

2.4.3. Mediation Model

The relationship between urban shrinkage and urban resilience involves a complex mechanism. In our study, we treated urban resilience as the dependent variable, while urban shrinkage served as the independent variable. Additionally, we included several intermediate variables to explore their mediating effects. These variables were innovation capability, cultural development, urbanization rate, and environmental quality. To operationalize these variables, we used the innovation index to measure innovation capability, the Baidu index of "city name + culture" [22] to gauge cultural development, the urbanization rate to assess the level of urbanization, and $PM_{2.5}$ emissions as an indicator of environmental quality. The mediation model can be represented by the following equation:

$$Y = \alpha_1 + cX + \varepsilon_1 \tag{4}$$

$$M = \alpha_2 + aX + \varepsilon_2 \tag{5}$$

$$Y = \alpha_3 + c'X + bM + \varepsilon_3 \tag{6}$$

In Equations (4)–(6), α_1, α_2, and α_3 are fixed intercepts; c, a, c', and b represent the total effect, distribution effect, direct effect, and indirect effect of variables, respectively; ε_1, ε_2, and ε_3 denote random disturbance terms.

2.5. Data Sources

The urban social and economic data used in this study were primarily obtained from sources such as the China Urban Construction Statistical Yearbook, China City Statistical Yearbook, Liaoning Statistical Yearbook, Jilin Statistical Yearbook, and Heilongjiang Statistical Yearbook for the relevant years. Additionally, statistical bulletins from the respective provinces or cities were consulted to gather specific information. NPP-VIIRS night-time light datasets were acquired from the National Centers for Environmental Information, which is under the purview of the National Atmospheric and Oceanic Administration. The innovation index utilized in this study was sourced from the Center for Enterprise Research at Peking University.

Urban shrinkage demonstrates a certain degree of cyclicality, and it is important to select an appropriate study period that captures relevant trends without being excessively long or short. Therefore, the period from 2012 to 2018 was chosen for this study. The year 2012 was selected as the starting point for several reasons. Firstly, it marked a turning point in China's economy, with key economic indicators such as GDP growth rate, industrial added value, fixed asset investment, total retail sales of consumer goods, and total imports and exports showing a downward trend. This shift indicated a transition from a phase of high-speed growth to one focused on high-quality development, placing increased emphasis on urban resilience. Additionally, by 2012, China's urbanization rate surpassed 50% (reaching 52.57%), signifying a significant milestone in the country's urbanization process. On the other hand, the year 2018 was chosen as the end year for two main reasons. Firstly, the outbreak of the COVID-19 pandemic in late 2019 had a predominantly short-term impact on urban population and economy. As the post-pandemic era witnessed a gradual recovery and resumption of growth, it was important to consider a period that reflected the pre-pandemic situation. Secondly, the pandemic posed a significant challenge to social and economic development, providing a critical test for urban resilience as a robust support system in the face of major shocks. To isolate the impact of urban shrinkage on urban resilience from the influence of the COVID-19 pandemic, the year 2018 was chosen as the end year. Furthermore, 2015 marked the transition between China's 12th and 13th Five-Year Plans. To delve deeper into the evolution of urban

shrinkage over time, the research period was divided into two shorter periods: 2012–2015 (T_1) and 2015–2018 (T_2). This division allows for a more detailed analysis of the dynamics and changes in urban shrinkage patterns.

3. Spatiotemporal Evolution of Urban Shrinkage and Urban Resilience

3.1. Spatiotemporal Evolution of Urban Shrinkage

3.1.1. Spatiotemporal Evolution Features

In the three provinces of Northeast China, a total of 18 cities experienced shrinkage between 2012 and 2018 (Table 3). It is worth noting that a significant proportion of these cities (32.35%) exhibited moderate levels of shrinkage. This suggests that extensive population reductions occurred as a consequence of urbanization in these provinces. Furthermore, over 40% of the cities experienced economy-related shrinkage, with nearly 30% of them facing severe shrinkage. This indicates that the three provinces were undergoing a smaller but more severe economic recession, accompanied by extensive population declines. On the other hand, the number of cities experiencing space-related shrinkage was comparatively lower, and most of these cities only experienced slight shrinkage. Notably, the overall number of cities exhibiting comprehensive shrinkage decreased from 20 in T_1 to 17 in T_2 (Tables 4 and 5), indicating that some cities in the three provinces experienced a degree of revitalization. The number of cities experiencing population-related shrinkage increased from 16 in T_1 to 30 in T_2, suggesting that the scope of population-related shrinkage became more extensive during the study period. This trend indicates a continued decline in the permanent and employed population of urban areas. Conversely, the number of cities with economy-related shrinkage decreased from 21 to 10, accompanied by reductions in severe, moderate, and mild shrinkage by 6, 5, and 1, respectively. Additionally, the number of cities with space-related shrinkage decreased from 13 to 7, with a corresponding decrease of 1 city in severe shrinkage, 3 cities in mild shrinkage, and 3 cities in slight shrinkage.

Approximately half of the cities in the three provinces were experiencing comprehensive shrinkage, with population-related shrinkage being the most prevalent. Economy-shrinking cities ranked second in terms of numbers, but they exhibited the most severe degree of shrinkage. On the other hand, space-shrinking cities were the least common, which was the least pronounced among the three dimensions. During T_1 and T_2, the number of comprehensively shrinking cities, economy-shrinking cities, and space-shrinking cities decreased, while the number of population-shrinking cities increased significantly. These findings align with previous research conducted by Yu et al. [45] on regional shrinkage in the three provinces of Northeast China. This observation underscores the significant impact that the expansion and shrinkage tendencies of urban areas, as the core of a region, can have on the entire region.

3.1.2. Spatial Differences in Urban Shrinkage

Between 2012 and 2018, the comprehensive shrinking cities in the three provinces were divided into two main areas (Figure 2): a large area encompassing Heilongjiang, Jilin, and Liaoning provinces, and a smaller area in the northeast of Heilongjiang Province. The focal point of the large area was Tieling, a city experiencing severe shrinkage, surrounded by moderately shrinking cities such as Fuxin, Anshan, and Dandong. The smaller area included resource-based cities such as Hegang, Shuangyashan, and Jixi. During the T_1 period, the shrinking area exhibited an inverted "L" shape in the south and a symmetrical pattern in the north. In the inverted "L"-shaped shrinking area, cities such as Tieling, Benxi, and Fuxin experienced moderate shrinkage, while Daqing, Siping, Fushun, Jinzhou, Panjin, and Yingkou showed mild and slight levels of shrinkage. In the northern shrinking area, which was located in the northeastern part of Heilongjiang Province, shrinking cities such as Hegang, Shuangyashan, and Qitaihe were distributed symmetrically. During the T_2 period, cities such as Hegang, Qitaihe, Yichun, and Shuangyashan that experienced shrinkage in T_1 did not shrink in T_2, and the shrinkage in Shuangyashan also eased. Cities such as Qiqihar, Baicheng, and Jilin experienced different levels of shrinkage.

Table 3. Statistical table of shrinking cities in the three provinces of Northeast China from 2012 to 2018.

	Severe Shrinkage		Moderate Shrinkage		Mild Shrinkage		Slight Shrinkage		Total	
	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)
Comprehensively shrinking city	1	2.94	11	32.35	3	8.82	3	8.82	18	52.94
Population-related shrinking city	2	5.88	13	38.24	7	20.59	4	11.76	26	76.47
Economy-related shrinking city	10	29.41	4	11.76	1	2.94	0	0	15	44.12
Space-related shrinking city	0	0	1	2.94	3	8.82	4	11.76	8	23.53

Table 4. Statistical table of shrinking cities in the three provinces of Northeast China from 2012 to 2015.

	Severe Shrinkage		Moderate Shrinkage		Mild Shrinkage		Slight Shrinkage		Total	
	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)
Comprehensively shrinking city	0	0	6	17.65	7	20.59	7	20.59	20	58.82
Population-related shrinking city	0	0	1	2.94	8	23.53	7	20.59	16	47.06
Economy-related shrinking city	10	29.41	6	17.65	3	8.82	2	5.88	21	61.76
Space-related shrinking city	1	2.94	0	0	4	11.76	8	23.53	13	38.24

Table 5. Statistical table of shrinking cities in the three provinces of Northeast China from 2015 to 2018.

	Severe Shrinkage		Moderate Shrinkage		Mild Shrinkage		Slight Shrinkage		Total	
	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)
Comprehensively shrinking city	1	0	3	8.82	7	20.59	6	17.65	17	50.00
Population-related shrinking city	3	0	10	29.41	13	38.24	4	11.76	30	88.24
Economy-related shrinking city	4	11.76	1	2.94	2	5.88	3	8.82	10	29.41
Space-related shrinking city	0	0	1	2.94	1	2.94	5	14.71	7	20.59

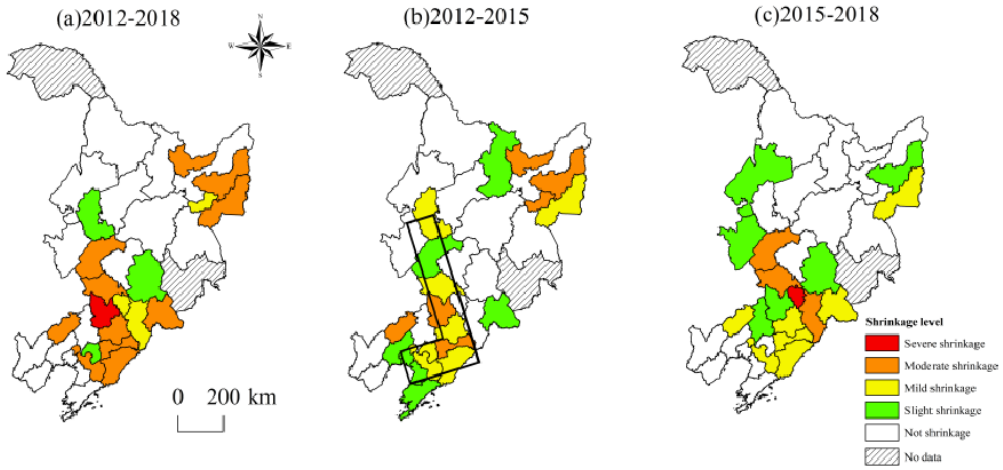

Figure 2. Spatial differences in comprehensively shrinking cities in the three provinces of Northeast China from 2012 to 2018.

From 2012 to 2018, population-related shrinkage in the three provinces exhibited a "barbell" pattern (Figure 3), with severe shrinkage in the south and north, and relatively milder shrinkage in the central region. In the southern area, moderately shrinking cities served as the central point, interspersed with severely and mildly shrinking cities. The northern region experienced both moderate and mild shrinkage. In contrast, the majority of cities in the central region did not experience shrinkage. During the T_1 period, population-related shrinkage was not widespread, but rather patchy in nature. Among the three provinces, Liaoning Province had the highest number of shrinking cities, totaling nine. However, in the T_2 period, shrinking cities became more widespread throughout the three provinces. With the exception of Suihua, Changchun, Yanbian, Panjin, and Dalian, the majority of cities experienced some degree of shrinkage. Cities with severe and moderate levels of shrinkage were primarily concentrated between Changchun and Dalian. Moreover, cities in the southwest of Liaoning Province and the northeast of Heilongjiang Province predominantly experienced moderate shrinkage, while slight shrinkage was primarily observed in cities located in the western region of Heilongjiang Province.

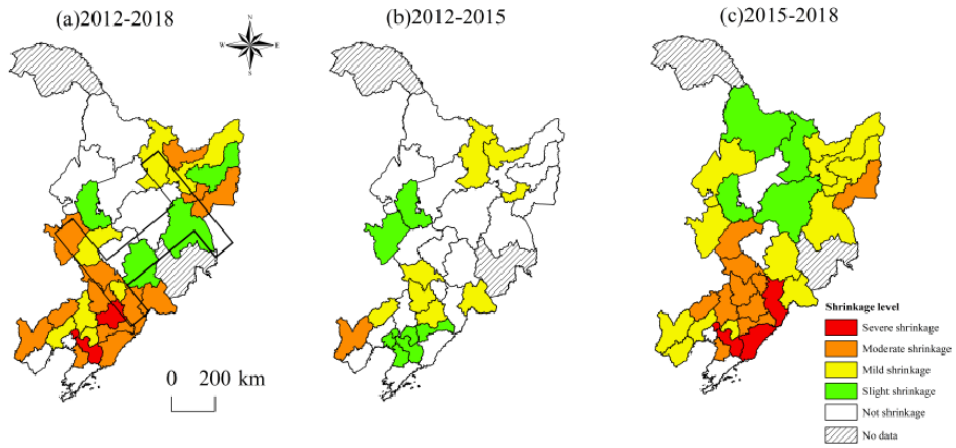

Figure 3. Spatial differences in population-shrinking cities in the three provinces of Northeast China from 2012 to 2018.

Despite being less widespread than population-related shrinkage, economy-related shrinkage was more severe (Figure 4). Cities experiencing economy-related shrinkage were primarily concentrated in Liaoning Province, the southern region of Jilin Province, and the northeastern part of Heilongjiang Province, with the most significant manifestation

occurring in the "Triangle" shrinkage zone at the border of Liaoning and Jilin. During the T_1 period, the extent and severity of economy-related shrinkage were significant, with 27.78% of cities experiencing severe shrinkage. In Liaoning Province, all cities except Chaoyang experienced economy-related shrinkage. The northeast of Heilongjiang Province was also experiencing severe shrinkage. However, during the T_2 period, the pace of economy-related shrinkage significantly slowed down. The evidence of economy-related shrinkage observed in the northeast of Heilongjiang Province during the T_1 period disappeared. Only Liaoning Province and Jilin Province continued to experience economy-related shrinkage. A "C"-shaped shrinkage zone formed at the border of Liaoning and Jilin provinces, representing the concentration of economic decline in the region.

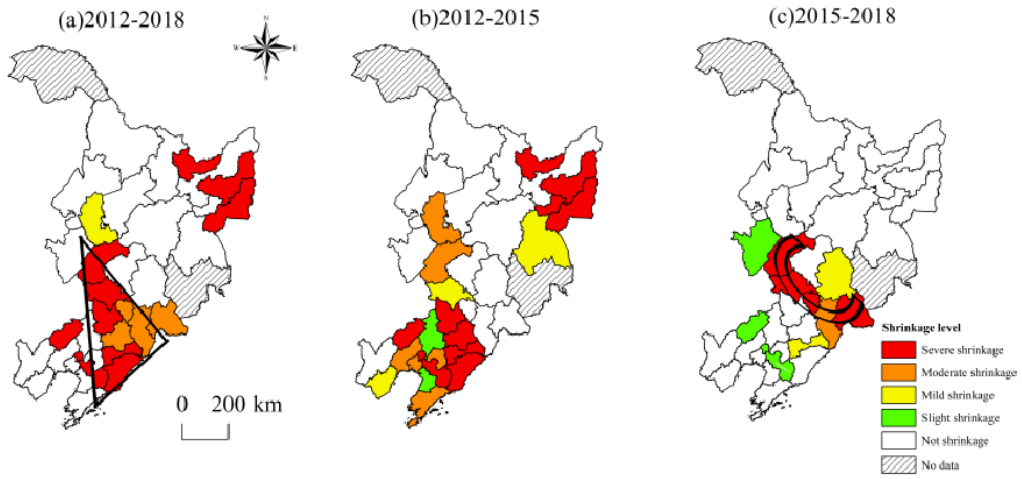

Figure 4. Spatial differences in economy-shrinking cities in the three provinces of Northeast China from 2012 to 2018.

The rigidity of urban expansion resulted in a scattering of cities experiencing space-related shrinkage, as illustrated in Figure 5. From 2012 to 2018, space-shrinking cities were most widely distributed in Heilongjiang Province. Among them, Shuangyashan experienced moderate shrinkage, while the remaining cities experienced mild and slight shrinkage. During the T_1 period, shrinking cities were widespread, but the majority of them experienced only slight levels of shrinkage. Shuangyashan was the only city in this period to experience severe shrinkage. However, during the T_2 period, there was a considerable reduction in space-related shrinkage, and cities with such shrinkage became scattered throughout the region.

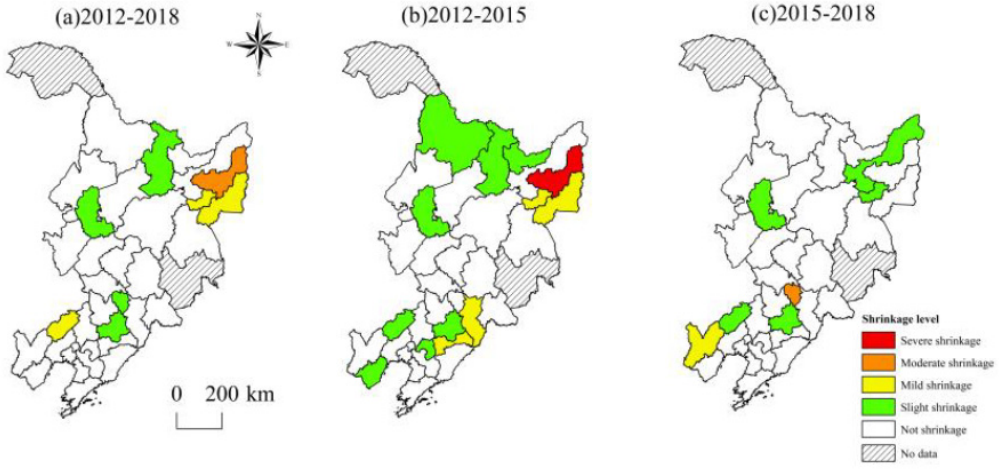

Figure 5. Spatial differences in space-shrinking cities in the three provinces of Northeast China from 2012 to 2018.

3.2. Spatiotemporal Evolution of Urban Resilience

3.2.1. Urban Resilience Tended to Be Balanced, with Economic Resilience Dominating

From a temporal perspective, there was a trend of narrowing differences between the three provinces of Northeast China, as indicated by the coefficient of variation dropping from 0.7007 to 0.6967 between 2012 and 2018 (Table 6). This trend suggests a more balanced development in urban resilience in the region. This finding contrasts with the research conducted by Chen et al. [37] on the urban resilience of the Harbin–Changchun City Cluster. Furthermore, the coefficients of variation for economic, social, and ecological resilience exhibited a shrinking trend, indicating a decrease in differences among cities in the three provinces in these areas. Notably, the coefficient of variation for economic resilience decreased significantly from 0.7057 to 0.5064. However, the coefficient of variation for infrastructure resilience showed an increase, highlighting a widening gap between cities in the three provinces. This disparity can be attributed to regional differences in the intensity of infrastructure development during the urbanization process.

Table 6. Coefficient of variation in urban resilience in the three provinces of Northeast China from 2012 to 2018.

	Urban Resilience	Economic Resilience	Social Resilience	Ecological Resilience	Infrastructure Resilience
2012	0.7007	0.7057	0.9662	0.6467	0.1214
2015	0.6990	0.6452	0.9403	0.6403	0.1344
2018	0.6967	0.5064	0.9130	0.5674	0.1489

During the temporal evolution of urban resilience, economic resilience consistently maintained its position as the foremost subsystem, with its standard deviation index increasing from 0.0253 to 0.0821. This highlights the crucial role of economic factors in driving the balanced development of urban resilience. Infrastructure resilience experienced a rise in rank from third to second place, indicating a growing influence of infrastructure construction on urban resilience. On the other hand, ecological resilience dropped from second to third place, signifying a diminishing impact on urban resilience. Social resilience remained at the bottom of the list, exerting the least influence on urban resilience. In summary, economic development and infrastructure construction emerge as significant factors in enhancing urban resilience in the three provinces of Northeast China. Despite China's strong emphasis on ecological civilization, there remains ample room for improvement in ecological resilience.

3.2.2. Spatial Differences in Urban Resilience Were Evident, and the Spatial Correlation Tended to Increase over Time

To explore the spatial variations in urban resilience further, the natural breakpoint method in ArcGIS software was utilized. This method allowed for the classification of the urban resilience index of the three provinces into three levels: high, moderate, and low (Figure 6). Cities with low resilience were primarily resource-based shrinking cities, including Anshan, Fushun, Benxi, Dandong, Fuxin, Tieling, Siping, Baishan, Songyuan, and Shuangyashan. Initially, these cities experienced development and expansion due to abundant mineral resources and a strong heavy industry foundation. However, they faced challenges such as overcapacity, a short and low-end industrial chain, and a lack of innovation and transformation capabilities. These issues were exacerbated by resource depletion, inefficiency, pollution, and a limited ability to innovate and transform. As a result, these cities struggled to meet the requirements of modern industries for transformation and upgrading. The development of emerging industries lagged behind, leading to insufficient employment opportunities. Additionally, many cities had a high concentration of state-owned enterprises and state-owned economies, which hindered reforms. With depleted resources and a single industrial structure, these cities had limited economic development and low resilience. Moderately resilient cities and highly resilient cities, on

the other hand, were mainly non-shrinking cities. Despite the overall regional shrinkage, these cities were able to maintain a certain level of economic growth capacity and resist certain risks. Among them, highly resilient cities were primarily the central cities of the region, such as Shenyang, Dalian, Changchun, and Harbin. This finding aligns with the research by Zhang et al. [38]. Most of these cities were provincial capitals or economically developed cities with advanced industrial structures. They fostered new economic development drivers through urbanization and underwent relatively rapid transformation and upgrading of their industrial structures. Consequently, they were better equipped to withstand risks effectively. During the research period, the global Moran's *I*, a measure of spatial autocorrelation, was greater than 0 and increased from 0.5372 to 0.5987, indicating a positive correlation between the urban resilience of the three provinces over time.

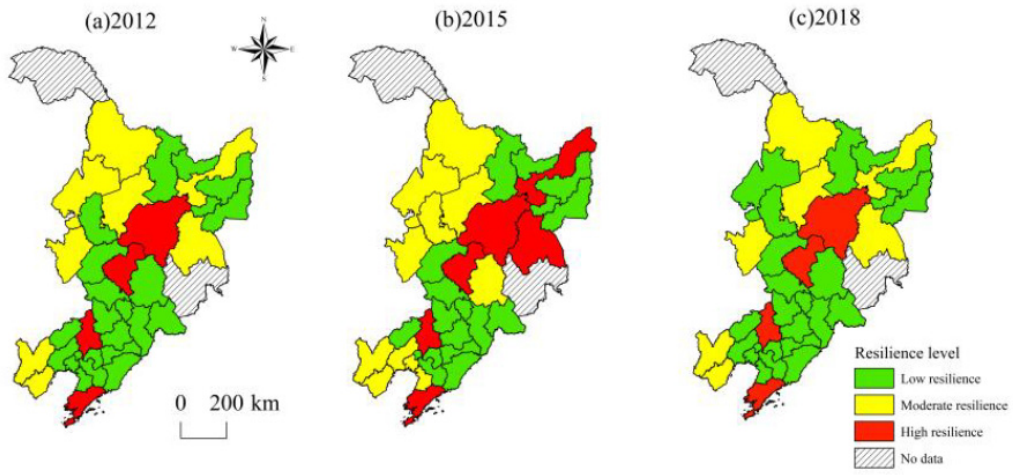

Figure 6. Spatial differences in urban resilience in the three provinces of Northeast China from 2012 to 2018.

3.2.3. There Were Differences in the Resilience of Shrinking Cities of Different Types, and Their Resilience Was Lower Than the Average Level

Based on the spatiotemporal analysis of urban resilience in the three provinces of Northeast China, it is crucial to examine the resilience levels of different types of shrinking cities. In general, shrinking cities displayed notably lower resilience compared to the average level of the three provinces, resulting in their low rankings. Cities such as Dandong, Shuangyashan, and Baishan, which experienced shrinkage in both T_1 and T_2, ranked 30th, 31st, and 32nd, respectively. Shrinking cities commonly faced the challenges of population decline, economic recession, spatial shrinkage, and inadequate levels of economic, social, ecological, and infrastructure resilience. Cities with shrinking populations and economies exhibited significantly lower economic resilience than the regional average, with the gap continuously widening. This suggests that the economic resilience of shrinking cities declined as a consequence of population reduction and economic recession. Furthermore, cities experiencing space-related shrinkage demonstrated notably lower infrastructure resilience compared to the regional average. This can be attributed to the contraction of built-up areas and the sluggish pace of infrastructure development in these cities.

4. The Impact of Urban Shrinkage on Urban Resilience

4.1. Correlation between Urban Shrinkage and Urban Resilience

To examine the relationship between urban shrinkage and urban resilience, Spearman's correlation analysis was conducted to quantify the correlation between the urban shrinkage index, its various dimensions, and the urban resilience index. The Spearman's correlation coefficient, ranging from −1 to 1, indicates the strength and direction of the correlation, with larger absolute values indicating a stronger correlation. Table 7 presents the Spearman's correlation coefficients between the urban shrinkage index and the urban

resilience index. Throughout the research period, the correlation coefficients for population, economy, and space remained positive, indicating a positive correlation between the urban shrinkage index and the urban resilience index. In other words, more severe urban shrinkage corresponded to lower urban resilience. This highlights the crucial role of urban resilience in achieving urban growth. Compared to the T_1 period, a slight decrease in the correlation coefficient was observed in the T_2 period. However, the highest correlation coefficient was consistently observed over the entire research period from 2012 to 2018, indicating a stronger correlation between urban shrinkage and urban resilience over a longer time frame. Hence, greater attention should be given to urban shrinkage and urban resilience over extended periods. The correlation coefficient between population-related shrinkage and urban resilience was the highest, and all coefficients passed the significance test at the 0.01 level. This suggests a robust correlation between population-related shrinkage and urban resilience. Given the widespread occurrence of population-related shrinkage in the three provinces of Northeast China, it is reasonable to prioritize efforts to enhance the resilience of this region.

Table 7. Spearman's correlation coefficients of urban shrinkage and urban resilience.

Period	Comprehensively Shrinking City		Population-Related Shrinking City		Economy-Related Shrinking City		Space-Related Shrinking City	
	Spearman's Coefficient	Sig.	Spearman's Coefficient	Sig.	Spearman's Coefficient	Sig.	Spearman's Coefficient	Sig.
2012–2015	0.364 **	0.034	0.920 ***	0.000	0.304 *	0.080	0.336 *	0.052
2015–2018	0.321 *	0.064	0.914 ***	0.000	0.303 *	0.081	0.182	0.304
2012–2018	0.444 ***	0.009	0.954 ***	0.000	0.441 ***	0.009	0.339 *	0.50

* denotes statistical significance at the confident level of 0.1; ** denotes statistical significance at the confident level of 0.05; and *** denotes statistical significance at the confident level of 0.01.

4.2. The Impact Path of Urban Shrinkage on Urban Resilience

Based on the analysis of the correlation between urban shrinkage and urban resilience, a mediation model was employed to provide further insights into the pathways through which urban shrinkage influences urban resilience. The effects, both total and distribution, of the variables are presented in Table 8. The correlation coefficient of the total effect revealed a significant positive relationship between the urban shrinkage index and the urban resilience index, aligning with the findings of Spearman's correlation analysis. Regarding the distribution effects, the urban shrinkage index exhibited a significantly positive correlation with urban innovation capability and cultural development. This implies that greater urban shrinkage corresponds to poorer urban innovation capability and cultural development. However, neither environmental quality nor urbanization demonstrated significant effects, indicating the need for further investigation into the impact of urban shrinkage on these factors.

Table 8. The total effect of urban shrinkage on urban resilience and its distribution effect on mediating factors.

Variable	Total Effect	Distribution Effect			
	Urban Resilience	Innovation Capability	Cultural Development	Urbanization	Environmental Quality
Urban shrinkage	0.726 *** (−2.733)	0.672 ** (−2.075)	0.507 ** (−2.061)	0.323 (−0.280)	0.128 (−0.434)
Constant	0.221 ***	0.321 ***	0.172 ***	0.433 ***	0.567 ***
R^2	0.189	0.119	0.117	0.04	0.006

** denotes statistical significance at the confident level of 0.05; and *** denotes statistical significance at the confident level of 0.01. T statistics is in parentheses.

To delve deeper into the direct and indirect effects of the variables, separate analyses were conducted for the four intermediary variables (Table 9 Models 1–4). Accordingly, the combined effects of the intermediary variables were examined (Table 9 Model 5). It was revealed that both cultural development and innovation capability had positive intermediary effects on urban resilience, with innovation capability exerting a stronger influence than cultural development. No conclusive evidence was found for a mediating effect from urbanization and environmental quality. However, both urbanization and environmental quality passed the significance test in Model 5, suggesting that they may indirectly contribute to urban resilience.

Table 9. The direct and indirect effects of urban shrinkage on urban resilience.

	Model 1	Model 2	Model 3	Model 4	Model 5	Mediating Effect
Urban shrinkage	0.712 *** (9.782)	0.945 *** (10.101)	0.673 *** (2.792)	0.765 *** (2.801)	0.528 *** (3.978)	
Innovation capability	0.247 * (1.736)				0.298 ** (2.690)	0.200 **
Cultural development		0.246 * (1.777)			0.292 ** (2.582)	0.148 **
Urbanization			0.121 (0.717)		0.206 ** (2.430)	0.026
Environmental quality				0.409 *** (2.833)	0.190 ** (2.466)	0.061
Constant	−0.008	0.058 **	−0.011	0.168 *	−0.165 **	
R^2	0.802	0.811	0.356	0.202	0.898	

* denotes statistical significance at the confident level of 0.1; ** denotes statistical significance at the confident level of 0.05; and *** denotes statistical significance at the confident level of 0.01. T statistics is in parentheses.

The urban shrinkage index demonstrated a noteworthy positive effect on innovation capability (0.672), and innovation capability, in turn, exhibited a positive correlation with urban resilience (0.298). Factors such as financial investment and the presence of high-quality talent are crucial in shaping urban innovation capabilities [46]. During the process of urban shrinkage, there is a loss of young and middle-aged labor, particularly high-quality talent, which subsequently results in a shortage of human resources for urban innovation and research and development. Furthermore, the decline in the urban economy, specifically the reduction in financial investment, undermines the city's capacity for innovation. Given the relatively high concentration of heavy industries in these three provinces, the decline in urban innovation capabilities hampers industrial restructuring and the transformation of economic development models. Consequently, these cities are less equipped to withstand external risks.

Urban shrinkage had an adverse impact on cultural development (0.507), whereas cultural development played a vital role in enhancing urban resilience (0.292). The emergence of the "Northeast Phenomenon" and "New Northeast Phenomenon" can largely be attributed to constraints arising from awareness and institutional mechanisms. The three provinces of Northeast China exhibit a homogeneous industrial structure, a significant presence of state-owned enterprises, and a slow pace of reform. The historical practice of extreme egalitarianism led to a stagnant mindset and a lack of innovation among the local residents. Moreover, the long-standing planned economy contributed to a rigid system and an underdeveloped private sector. As a consequence, their economic development is severely constrained, resulting in an unfavorable situation.

The regression results indicate that urbanization and environmental quality did not exhibit a significant mediating effect. The impact of urban shrinkage on urbanization did not meet the threshold for statistical significance. As cities experience shrinkage accompanied by population decline and limited economic development, their attractiveness diminishes, hindering the urbanization process to some extent. The three provinces of Northeast China

are currently in the midst of rapid urbanization, with large numbers of rural residents migrating to urban areas, leading to a continuous increase in the urbanization rate. This trend has a certain inhibitory effect on urban shrinkage, particularly in terms of population-related shrinkage. The urbanization rate in the three provinces consistently rose during the research period. Considering the significant population decline, it is likely that the severe population-related shrinkage in these provinces can be attributed to several factors. Firstly, the three provinces experienced negative natural growth rates for many years, and the urban population's natural growth rate was sluggish. Consequently, urban populations are relocating outward, particularly in Heilongjiang Province.

Environmental quality did not exhibit a significant mediating effect, as its distribution effect did not meet the threshold for statistical significance. Urban shrinkage is frequently linked to the reduction in industrial production scales, especially the decline in polluting industries. This can lead to an improvement in environmental quality, which, in turn, can impact urban shrinkage. Enhanced environmental quality has the potential to enhance the city's attractiveness, attract both residents and foreign investors, and mitigate urban shrinkage to some extent. This inhibitory effect can largely offset the influence of urban shrinkage on environmental quality, resulting in the failure of its distribution effect to meet the significance test.

5. Discussion

5.1. Different Impacts of Various Dimensions of Urban Shrinkage on Urban Resilience

Urban shrinkage encompasses various dimensions, such as population, economy, and space, each with its distinct influence on urban resilience. To delve deeper into the impact of these dimensions on urban resilience, a mediation model was employed to assess the total effect, distribution effect, direct effect, and indirect effect of population-related shrinkage, economy-related shrinkage, and space-related shrinkage. These measurements were derived from the findings of Spearman's correlation analysis. The results are presented in Table 10.

Table 10. The direct and indirect effects of various dimensions of urban shrinkage on urban resilience.

	Urban Resilience		Innovation Capability		Cultural Development		Urbanization Rate		Environmental Quality	
	Total Effect	Direct Effect	Allocation Effect	Indirect Effect	Allocation Effect	Indirect Effect	Allocation Effect	Indirect Effect	Allocation Effect	Indirect Effect
Population-related shrinkage	0.908 ** (2.652)	0.306 ** (−2.124)	0.765 * (1.817)	0.336 *** (−2.962)	0.659 ** (2.092)	0.513 *** (−3.694)	0.247 (0.680)	0.158 (−2.047)	0.276 (0.735)	0.167 (−1.958)
Economy-related shrinkage	0.582 * (1.820)	0.118 ** (−2.209)	0.892 ** (2.479)	0.311 * (−2.748)	0.221 (0.747)	0.528 *** (−3.860)	0.851 *** (2.951)	0.181 ** (−2.297)	0.922 *** (3.133)	0.221 ** (−2.469)
Space-related shrinkage	0.258 * (2.000)	0.211 (−1.297)	0.216 (1.392)	0.270 ** (−2.077)	0.196 (1.680)	0.632 *** (−4.205)	0.083 (0.634)	0.167 (−1.991)	0.070 (0.516)	0.144 (1.608)

* denotes statistical significance at the confident level of 0.1; ** denotes statistical significance at the confident level of 0.05; and *** denotes statistical significance at the confident level of 0.01. T statistics is in parentheses.

Population-related shrinkage exhibited the highest total and direct effects among the three dimensions of urban shrinkage, aligning with the findings of Spearman's correlation analysis. Following this were economy-related shrinkage and space-related shrinkage. Population decline is a crucial characteristic of urban shrinkage and significantly impacts the resilience of cities. Notable manifestations include a remarkably low birth rate, the loss of young and middle-aged labor force and high-quality talent, as well as a high proportion of elderly population in the three provinces. These factors led to insufficient labor supply, increased burdens on social assistance, and heightened risks of population decline [47,48]. These conditions are detrimental to the sustainable development of urban resilience. Regarding population-related shrinkage, the overall mediating effects of innovation capability (0.257) and cultural development (0.338) were statistically significant. Population plays a vital role in technological innovation and cultural development. With a decrease in

population, particularly the loss of high-quality talent, the essential resources necessary to support technological innovation and cultural development diminished. However, urbanization and environmental quality did not pass the significance test. One primary reason for this is that as urbanization rates increase and environmental quality improves, there is an inhibitory effect on population-related shrinkage, which mitigates some of its negative effects on urbanization and environmental quality. Concerning economy-related shrinkage, the overall mediating effects of innovation capability (0.377), urbanization (0.154), and environmental quality (0.204) all passed the significance test. Several factors contribute to the decline in urban innovation capabilities, including the reduction in the urban economic scale, financial decline, and decreased expenditures on science and technology [49]. Economic development, as an endogenous force of urbanization, enhances a city's resilience to risk by increasing the urbanization rate and population. Moreover, the economic development of a city strengthens its resilience to risk by increasing the urbanization rate and population density. Regarding space-related shrinkage, innovation capability exhibited a complete mediation effect (0.058), implying that innovation capability can directly impact urban resilience.

5.2. The Path to Improve Resilience in Shrinking Cities

As a preliminary path, embracing the concept of smart shrinkage and promoting the sustainable development of urban resilience is crucial. Blindly pursuing urban growth and expansion within the confines of the traditional growth model undermines the long-term sustainability of urban resilience. Therefore, it would be prudent for the three provinces of Northeast China to draw lessons from the experiences of Western countries in managing urban shrinkage and employ smart shrinkage strategies to rejuvenate shrinking cities. Optimizing urban population and economic factors is paramount to align with the trajectory of urban development. Guiding the outward migration of the population from shrinking cities in accordance with their carrying capacity is essential. In order to curb the extensive development pattern of cities, it is imperative to develop and utilize existing land resources and establish a land bank to repurpose industrial waste land into green spaces [50]. This approach not only enhances the urban environment, but also provides land for future development.

Another avenue to pursue is increasing investment in science and technology to enhance innovation capabilities. Innovation capability plays a crucial role in the relationship between urban shrinkage and urban resilience. To achieve this, it is necessary to leverage the government's effective macro-control measures and ensure the prudent utilization of fiscal resources to continuously invest in science and technology. As part of industrial structure upgrading, it is vital to fully harness technological innovation, bolster the capacity of universities, colleges, and research institutes to translate innovative achievements into practical applications, implement strategies for industrial rejuvenation, and encourage the modernization of both traditional and emerging industries. Emphasizing technological transformation and equipment renewal is imperative. Strengthening the integration of new-generation information technology with traditional industries is vital to enhance the competitiveness of established sectors. Additionally, fostering professional agglomeration, nurturing emerging industries, and establishing robust and competitive industrial clusters are essential steps to cultivate continuous and viable alternatives to traditional industries [51].

The third crucial path involves enhancing the resilience of cities and their capacity to effectively manage risks. The construction of resilient cities plays a pivotal role in mitigating urban shrinkage caused by natural disasters, a dependence on a single industry, and inadequate urban development potential [52]. To achieve this, it is imperative to leverage information technologies, such as big data and the Internet of Things, to facilitate the seamless integration of resilient city construction with the concepts of sponge cities and smart cities. Employing a comprehensive approach, cities can bolster their resilience in terms of economy, society, ecology, and infrastructure. Furthermore, establishing a

collaborative governance network among various stakeholders is paramount for promoting the coordinated development of urban resilience in the three provinces of Northeast China.

5.3. Limitations and Prospects

In China's existing administrative division system, a city is always divided into its administrative territory (the administrative area under the city's jurisdiction) and its physical territory (the urban built-up area and urbanization area). For the purpose of this study, focusing on the "urban area" closest to the statistical definition of a "city" is both appropriate and feasible. However, when identifying specific physical cities in the future, it is crucial to consider the unique national conditions of China, as this will form the foundation for future research on urban shrinkage in the country. It is important to note that this study only examines the period from 2012 to 2018, and the observed characteristics and patterns of urban shrinkage and urban resilience are thus limited to this timeframe. The impact of urban shrinkage and urban resilience under the COVID-19 pandemic is yet to be extensively explored. Investigating the growth or shrinkage patterns of different cities and the post-pandemic recovery and development of urban resilience are valuable avenues for future research. Moreover, it would be intriguing to examine the specific features of urban shrinkage at a finer scale in future studies.

6. Conclusions

This study builds upon a comprehensive evaluation index system for assessing urban shrinkage and urban resilience in the three provinces of Northeast China. It aims to investigate the spatiotemporal dynamics of urban shrinkage and urban resilience, analyze their correlation using the Spearman's coefficient, test the impact pathways of urban shrinkage on urban resilience through a mediation model, and propose strategies to enhance resilience in shrinking cities. These findings contribute to the theoretical understanding of urban shrinkage and urban resilience, furthering our knowledge of their relationship. The research results provide valuable references for decision-making processes aimed at improving the resilience of shrinking cities in the three northeastern provinces, facilitating their transformation and promoting high-quality development. The main conclusions drawn from this study are as follows:

(1) Urban shrinkage was a prominent phenomenon in the three provinces of Northeast China, exhibiting significant spatiotemporal variations across different dimensions of shrinkage. More than half of the cities in these provinces were experiencing shrinkage, although the implementation of the Northeast revitalization strategy led to a narrowing of the shrinkage scope. Among the various dimensions, population-related shrinkage was the most widespread, with the number of shrinking cities continuing to increase. These shrinking cities were concentrated in both the northern and southern regions. Economy-related shrinkage was particularly severe, especially in Liaoning Province, although there were some indications of relief in the shrinkage trend. Space-related shrinkage showed a relatively moderate pattern, with shrinking cities dispersed throughout the region.

(2) There was notable spatiotemporal variation in urban resilience across the three provinces of Northeast China, particularly in shrinking cities where resilience was comparatively lower. The coefficient of variation indicates a decreasing trend, suggesting a more balanced development of urban resilience, with economic resilience consistently ranking first. In spatial terms, there was a significant positive correlation that tended to strengthen over time. The resilience of shrinking cities fell below the average level, with cities facing population-related and economy-related shrinkage showing the lowest levels of economic resilience, and this trend was declining. Among these, space-shrinking cities exhibited the weakest infrastructure resilience.

(3) The urban shrinkage index showed a significant positive correlation with the urban resilience index, indicating that different dimensions of urban shrinkage have varying impacts on urban resilience. Firstly, the Spearman's correlation coefficient

between the urban shrinkage index and the urban resilience index was positive. Secondly, urban shrinkage could directly or indirectly influence urban resilience. It could directly decrease urban resilience and could also exert an impact through intermediate factors such as innovation capacity and cultural development, further hindering urban resilience. Lastly, among the different dimensions of urban shrinkage, population-related shrinkage had the most pronounced impact on urban resilience. All three dimensions could directly impair urban resilience, but the influence on urban resilience through intermediate variables differed.

This study scrutinizes the spatiotemporal evolution of urban shrinkage and resilience preceding the COVID-19 pandemic. The dynamics in urban shrinkage and resilience during the pandemic, along with the exploration of resilient urban development to mitigate "urban crises" such as the COVID-19 pandemic and urban shrinkage, are central to our forthcoming research. Indeed, the COVID-19 pandemic exerted impacts of varying magnitudes on both urban shrinkage and resilience. The pandemic amplified the negative population growth in cities and impeded the process of urbanization [53], potentially exacerbating urban shrinkage. Cities exhibited diverse levels of resilience in response to the COVID-19 pandemic [54,55]. However, the evolution of urban resilience is a dynamic process of adjustment, with many cities rebounding to pre-pandemic levels or even beyond [56]. Gradual attention is also being directed towards resilient urban planning [57], with its focus broadening from natural disasters to public health and safety. In summary, the spatiotemporal differentiation of urban shrinkage during and subsequent to the COVID-19 pandemic, coupled with the planning and construction of resilient cities, carries both theoretical and practical implications and should be the primary focus of attention.

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