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The Impact of Urban Shrinkage on Carbon Emission Intensity and Its Spatial Spillover Effects

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Abstract: Cities are important consumers of resources, and their carbon emissions are key to realizing China's dual-carbon goals. However, the trend of urban shrinkage has grown increasingly pronounced in recent years, and how this affects the carbon emissions of cities is a major issue that deserves to be studied. This study zeroes in on 278 Chinese cities that rank at or above the prefectural level between 2012 and 2021, employs a comprehensive analytical framework, incorporating multiple methodological approaches including entropy-based measurement, panel fixed-effects regression, mediating effect analysis, and spatial econometric modeling, to systematically investigate how urban shrinkage affects carbon emission intensity. The study's findings indicate the following: (1) Urban contraction exacerbates the further increase in carbon emission intensity. (2) Mechanism tests show that human capital level and industrial structure advancement are the primary pathways through which urban shrinkage influences carbon intensity. (3) Urban contraction has a greater effect on increasing carbon emission intensity in central, western, and resource-dependent cities, according to the heterogeneity study. (4) Urban shrinkage lowers nearby cities' carbon intensity through spatial spillovers.

Keywords: urban contraction; carbon intensity; mechanisms; heterogeneity analysis; spatial spillover effects

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1. Introduction

In recent decades, China has achieved significant advancements in industrialization and urbanization. While its economy has achieved world-renowned success, carbon dioxide (CO_2) emissions have also grown rapidly. Speaking as a responsible global player, Chinese President Xi Jinping announced at the 75th UN General Assembly that China would aim to hit peak carbon dioxide emissions by 2030 and strive for carbon neutrality before 2060 [1]. China's economic expansion is largely propelled by urbanization, a process that also contributes to the lion's share of the country's CO_2 output [2]. Therefore, reaching the carbon peak and carbon neutrality milestones hinges on the cities. However, while China is experiencing rapid urbanization, due to the aging population, inefficient industrial structure, and the center city agglomeration effect, more and more cities are facing urban decline.

According to the standardized criteria developed by the Shrinking Cities International Research Network (SCiRN), a widely recognized scholarly framework characterizes urban contraction as occurring in settlements exceeding 10,000 inhabitants that exhibit persistent demographic reduction spanning at least two successive years, alongside structural economic deterioration [3]. Urban population declines are occurring in cities across North America, Europe, and even developing nations [4]. As a developing nation, China has faced

slowing population growth—and even a decline in some urban areas—with many cities experiencing population loss [5–7]. In northeast China, such as Daqing, Fuxin, Yichun, and other resource-oriented cities, the problem of urban shrinkage is more serious [8,9]. Given this context, cities play a pivotal role in attaining carbon peak and neutrality objectives. A systematic examination of how urban decline affects carbon footprints, along with an elucidation of the underlying causal pathways, is crucial for developing evidence-based strategies to enhance low-carbon urban development.

As the research progresses, scholars' studies on urban shrinkage have become increasingly rich, primarily concentrating on defining the meaning of the term "urban shrinkage", urban shrinkage phenomenon causes and impacts of the analysis, and so on. First, for the definition of the connotation of urban contraction, most scholars define urban contraction at the level of population size indicators. Fernandez et al. [10] have argued that urban contraction is essentially due to the continuing decline in population; Murdoch [11] pinpointed declining urban areas in the United States through population decline rate assessments. Other scholars have argued that urban shrinkage should not be defined only in terms of population but should also take into account various aspects such as the economy, social services, and urban infrastructure development. Saraiva et al. [12] have argued that if the definition of urban shrinkage only centers on population, it will change the scope of urban shrinkage. Therefore, an in-depth analysis of the phenomenon of urban contraction, combined with indicators of economic and social development, such as urban GDP, is necessary. Several researchers have emphasized the multidimensional nature of urban contraction, conceptualizing it as a composite phenomenon encompassing demographic depletion, economic downturn, employment contraction, and societal issues [13]. Second, there are similarities and contrasts between the elements driving urban contraction domestically and internationally when examining the factors influencing the phenomena of urban shrinkage. The main causes of the West's urban decline are demographic changes due to aging and declining fertility rates [14], the decline of central urban areas due to suburbanization, and the difficulty of cities to maintain their competitive advantages in future development due to de-industrialization [15], and the loss of competitive and comparative advantages due to the change in the world's division of labor pattern as a result of globalization [16]. The reasons for the contraction of Chinese cities lie in the worsening demographic aging [17], unbalanced industrial composition [18], accelerated urban growth [19], and outdated infrastructure [20]. Finally, a few scholars also analyze the impact of urban shrinkage, such as Wang et al. [21], who proposed that when a city experiences contraction, highly skilled labor will flow to other cities, fundamentally weakening the initiative and competitiveness of the city in industrial advancement and modernization, and seriously impeding the development of the regional economy. Bernt [22] proposed that urban contraction leads directly to a decline in human capital, making cities uncompetitive, economic downturns, and lower tax revenues. Among them, examining the connection between the phenomenon of urban shrinkage and carbon emissions is one of the topics that has garnered much scholarly attention recently, and many scholars have initiated preliminary discussions on the relationship between the two. Some scholars believe that a decrease in urban population density reduces the pressure on natural resources, reduces energy consumption, lowers the intensity of industrial production, and reduces the amount of traffic on roads, all of which promote the early realization of carbon neutrality [23,24]. Despite these insights, however, most studies have confirmed that cities experiencing population contraction phenomenon face problems such as continuous population decline, difficulties in economic transformation, and declining economic vitality, with a high proportion of traditional industries, low energy utilization efficiency, and a trend of continuous increase in carbon emissions [25]. Xiao et al. [26] conducted a study analyzing the carbon emission trends across 55 Chinese

cities, distinguishing between those experiencing population growth and those in decline. Their findings revealed that cities with shrinking populations consistently exhibited a steady rise in carbon emissions over time. Yang et al. [27] analyzed urban panel data across China between 2012 and 2019, revealing that shrinking cities experienced a steady rise in carbon emissions over this period. Their research identified population density, industrial composition, and municipal service provision as key drivers behind this upward trajectory in emissions for contracting urban areas. Scholars such as He et al. [28] utilized urban population and population density data from Japan between 2010 and 2020, categorizing urban development models into growth-oriented, potential contraction-oriented, intelligent contraction-oriented, and continuous contraction-oriented types. The research findings indicated that the carbon emissions of contraction-oriented cities were higher than those of growth-oriented cities.

The existing relevant literature lays the groundwork for the current research work, but there are some shortcomings. Firstly, in defining the level of urban contraction, most scholars use the change of population index to measure whether the city is contracting, which is controversial. Secondly, the existing literature lacks an in-depth analysis of the impact of urban contraction on carbon emission intensity, failing to adequately explore the underlying mechanisms at play. Furthermore, less attention is paid to the spatial spillover effect and heterogeneity study of how urban contraction affects carbon emissions. Finally, analysis of China's 2010 and 2020 national census data reveals that approximately 69% of Chinese cities experienced a population decline during this decade, based on the sixth and seventh nationwide demographic surveys. Compared with the number of cities that experienced shrinkage between 2000 and 2010, it increased by 86 [29]. China's urban shrinking situation is getting worse, and it requires us to conduct further analysis and discussion on it. Therefore, the study involves 278 Chinese prefecture-level and higher cities from 2012 to 2021 as the case study sample, defines urban shrinkage from multiple dimensions, and explores the direct relationship between urban contraction and carbon emission intensity, the mechanism of action, heterogeneity analysis, and spatial spillover effects, which can not only deepen the research on the problem of urban shrinkage but also provide certain theoretical references to the urban carbon emission reduction. This study makes some unique contributions as follows: (1) Employing a multidimensional assessment framework, this research develops a composite indicator incorporating social structure, economic, and population dynamics to quantify urban contraction severity, which can identify the level of urban contraction more comprehensively and accurately. (2) Using the human capital level and industrial structure upgrading as mediating variables, we analyze the mechanism of urban contraction's impact on carbon emissions. (3) This study conducts a comprehensive analysis of the differential effects that urban contraction exerts on CO_2 output across various spatial and urban types contexts. (4) Employing a spatial econometric framework, this research applies the spatial Durbin model to investigate how urban decline influences carbon emissions in neighboring jurisdictions through cross-regional diffusion processes.

2. Theoretical Analysis and Exploration

2.1. The Direct Impact of Urban Shrinkage on Carbon Emission Intensity

The development of a city requires the participation of various elements such as capital, land, technology, and talent, the process of a city's development is the process in which these elements flow and gather within the city [30]. Therefore, the contraction of the city is not only the reduction in the population but also includes the loss of capital, technology, and other elements. Shrinking cities will face a decrease in population size, a shift of industries outward, and a decrease in the density of socio-economic activities

in the city, etc. Lower population and economic activity densities can lead to problems such as imbalance in work and housing, longer commuting times, and more transportation and energy consumption. Especially in the current situation where many Chinese cities are experiencing population decline, urban space is still being continuously expanded in an attempt to boost economic development. Urban contraction can lead to higher urban vacancy rates, which is not conducive to the sharing of transportation, energy, and other facilities, as well as the centralized regulation of environmental pollution. They will lead to problems such as overcapacity and inefficient utilization of energy facilities, resulting in wasted energy and increased pollution emissions. All of which will stimulate a rise in carbon emissions. The following hypothesis is thus proposed:

Hypothesis 1 (H1). *Urban contraction leads to an increase in urban carbon intensity.*

2.2. The Mechanism Analysis of the Impact of Urban Shrinkage on Carbon Emission Intensity

One of the main characteristics of urban contraction is population loss, which impacts both the level of urban human capital and the amount of urban labor supply. The labor force tends to go to economically active areas, especially high-quality and high-skilled personnel, who have more autonomy in job choice and destination and are more likely to flow out [31]. According to the theory of endogenous growth, human capital is a key element in promoting social and economic development. The loss of talent in shrinking cities will impede the upgrading of production processes and technologies, further increasing the difficulty for enterprises to be able to make use of advanced, green production technologies and to accumulate the corresponding management experience, and making it difficult for enterprises to achieve the goal of low energy-consuming and low-emission production. At the same time, the loss of talent cannot form the learning, matching, and sharing of knowledge [32], and the spillover effect of knowledge decreases, resulting in a waste of resources and inhibiting scientific and technological innovation. The following hypothesis is thus proposed:

Hypothesis 2 (H2). *Urban contraction increases carbon emission intensity by inhibiting the rise in the level of urban human capital.*

On the one hand, population loss and dispersion can lead to an exodus of industries [4]. Shrinking cities with declining population and economic vitality will directly affect the city's economic activities and industrial demand, especially the service industry, which is dependent on the size of the population, faces the risk of closure or transfer to the neighboring developed cities while leaving behind a number of backward industries that are energy-consuming, highly polluting, and economically inefficient that are not accepted by other cities and are difficult to transfer outward, leading to irrational industrial structure of cities and stimulating the upward trend in carbon emissions. On the other hand, urban areas experiencing demographic contraction and economic stagnation face significant challenges in maintaining technological innovation capabilities and achieving industrial transformation, and the industrial structure is difficult to optimize and upgrade, which is not conducive to reducing energy dependence and leads to increased carbon emissions. The following hypothesis is thus proposed:

Hypothesis 3 (H3). *Urban contraction increases carbon emission intensity by hindering the upgrading of the industrial structure.*

2.3. The Spatial Spillover Effects of Urban Contraction on Carbon Emission Intensity

When a city undergoes contraction, neighboring cities often become the primary destination for the transfer of urban population, capital, technology, and various factors due to their geographic convenience. The demographic expansion of adjacent urban centers

helps realize economies of scale and spatial clustering benefits, share urban infrastructure and public services, and promote the formation of agglomeration economies such as knowledge spillovers and labor pools, thus reducing energy consumption and improving urban productivity [33]. In order to seek a better business environment and development opportunities, enterprises usually move to neighboring developed cities, forming industrial agglomerations in neighboring cities. On the one hand, enterprises can share resources such as knowledge and technology. When various innovation entities gather together, it can enhance the efficiency of technological advancement processes while accelerating the translation of scientific discoveries into practical applications. On the other hand, enterprises share the cost of pollution control by sharing pollution control facilities and other infrastructures, which can effectively cut pollution control expenses and promote energy saving and emission reduction [34]. In addition, government policies and planning and improved transportation infrastructure will also strengthen the effect of urban contraction on the carbon emission density of neighboring cities. For example, regional coordinated development policy facilitates the movement of factors such as population and capital between cities [35]; improved transportation infrastructure speeds up the flow of various resources between cities [36]. The following hypothesis is thus proposed:

Hypothesis 4 (H4). *Urban contraction reduces the carbon emission intensity of neighboring cities through spatial spillover effects.*

3. Materials and Methods

3.1. Variable Selection

(1) Dependent Variable: carbon dioxide emission intensity (CI)

Referring to the related study [37], this study uses prefecture-level city carbon emissions (CE) as the base dataset. Drawing insights from the studies of Cong et al. [38], the aggregate urban CO_2 emissions are derived by summing the emissions computed from the three categories of regional Scope 1, Scope 2, and Scope 3. Additionally, determine the city's carbon intensity (CI) by dividing its total carbon emissions by its regional GDP, or CO_2 emissions per GDP unit, the specific formula is as follows:

$$CI_{it} = CE_{it}/GDP_{it} \quad (1)$$

(2) Core Explanatory Variable: urban shrinkage (SK)

The development of the urban contraction indicator system continues to be a contentious topic in the academic community. Most scholars believe that the core feature of urban contraction is the decrease in population size and therefore use a single population indicator to identify the degree of urban contraction. Luo et al. [39] employed population change rates to assess urban shrinkage, and Heim LaFrombois et al. [40] used the decline in population as a core indicator to define and measure urban contraction. However, some researchers contend that urban decline is a multifaceted phenomenon not fully measurable by a single-metric approach [41]. In this paper, we refer to the relevant literature [42,43] to build the indicator system from the demographic, economic, and social dimensions, respectively (see Table 1). Population contraction is measured from the resident population in urban areas, population density, and juvenile population dependency ratio; economic contraction selects per capita GDP, per capita financial income, GDP growth rate, etc., as the indicators; social contraction selects per capita road area in the city, gas penetration rate, water penetration rate, etc., as the indicators.

Table 1. System of urban shrinkage indicators.

Target Level	Standardized Layer	Indicator Layer	Interpretation of Indicators (Unit)
Demographic	Size of population	Population in urban areas	Urban population (ten thousand people)
	Population density	Population density in urban areas	Population density in urban areas (persons/km^2)
	Population structure	# Adolescent dependency ratio	Number of students enrolled in primary and secondary schools/Number of employees in the unit at the end of the year (%)
Economics	Economic level	GDP per capita	GDP per capita (CNY)
		Fiscal revenue per capita	Income from the general budget of the local treasury/total population (CNY)
	Economic growth	GDP growth rate	The rate of GDP growth (%)
	Economic structure	# Employment structure	Number of employees in secondary industry/Number of employees in units at the end of the year (%)
		Industrial structure	Value added of tertiary industry/Value added of secondary industry (%)
Societies	Infrastructure	Transportation	Road area per capita (square meters)
		Social service	Gas penetration rate (%)
			Water penetration rate (%)
	Social environment	Environment	Greening coverage of built-up areas (%)
		Living environment	Urban residential land area/Total population (square meters)
		Urban space	Urban built-up area (square kilometers)

Note: "#" stands for negative indicators.

(3) Mediating Variables: level of human capital (Hc); upgrading of industrial structure (UIS)

Referring to the findings of the established literature [44,45], this study views the percentage of students enrolled in general tertiary schools relative to the whole population as a stand-in variable for the intermediate variable of human capital level, and the ratio of the added value of the tertiary industry to that of the secondary industry is selected as the proxy variable of the intermediate variable of industrial structure upgrading.

(4) Control Variables

Following the research approach of relevant scholars [46–48], economic development level (Econ) is measured by per capita gross regional product; the population size (People) is expressed by the number of residential population at the end of the year in the region; the urbanization rate (Urban) is expressed by the ratio of the area of the built-up area of the city to the total area of the region; the industrial structure (Indus) is measured by the secondary industry's value-added share of GDP; the government intervention (Govern) is expressed by the proportion of local general public budget expenditure to the GDP; social consumption level (Consumption) selects the proportion of total retail sales of consumer goods to GDP to express; and the level of the labor force (Labor) is the aggregate count of urban workers at the end of the year.

In order to eliminate the influence of heteroscedasticity, the non-ratio variables are treated logarithmically.

3.2. Entropy Method

(1) Standardized treatment

Referring to the research of related scholars [25], the indicators were standardized using the method of polar deviation, and the specific process was as follows:

$$X'_{ij} = \begin{cases} \frac{X_{ij} - \min X_j}{\max X_j - \min X_j} & \text{Positive indicators} \\ \frac{\max X_j - X_{ij}}{\max X_j - \min X_j} & \text{Negative indicators} \end{cases} \quad (2)$$

In Equation (2), X'_{ij} is the standard value; X_{ij} is the original value of the jth indicator value of the ith evaluation unit; and $\max X_j$, $\min X_j$ are the maximum and minimum values of the jth indicator, respectively.

(2) Calculate the weight of the jth indicator value of the ith evaluation unit:

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}} \quad (3)$$

(3) Calculate the information entropy of the indicator:

$$e_j = -k \sum_{i=1}^{m} P_{ij} \times \ln P_{ij}, k = \frac{1}{\ln(m)} \quad (4)$$

(4) Calculate information redundancy:

$$d_j = 1 - e_j \quad (5)$$

(5) Determination of indicator weights:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

(6) Calculate the composite development index for the ith city:

$$UDI_i = \sum_{j=1}^{n} W_j \times X'_{ij} \quad (7)$$

(7) Calculate the level of contraction of the city:

$$SK_i = -(UDI_{it} - UDI_{i2011}) \quad (8)$$

A negative sign is introduced in Equation (8), when $(UDI_n - UDI_{2011} < 0)$, cities experience contraction phenomena $(SK_i > 0)$, and the larger the value of SK_i, the more severe the decline in the level of urban development in the reporting period compared with the base period, i.e., the higher the level of urban contraction; conversely, the lower the level of urban contraction. The article uses 2011 as the base year and then measures the city contraction level in each year of 2012–2021 compared with the base year 2011.

3.3. Model Setting

Referring to the relevant literature [49], a bidirectional fixed-effects panel regression model is first constructed to test the impact of urban shrinkage on carbon emission intensity, which is set as follows:

$$CI_{it} = \beta_0 + \beta_1 shrink_{it} + \gamma control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (9)$$

In Equation (9), CI_{it} is the carbon intensity; $shrink_{it}$ is an indicator of urban contraction; $control_{it}$ is a set of control variables; μ_i is an individual fixed effect for cities; λ_t is a time fixed effect for years; ε_{it} is the random error term; subscript i is the city and t is the year; β_0 is a constant term; β_1 represents the core variable's coefficient; and γ is the correlation coefficient for every control factor.

Secondly, to test Hypothesis 2 and Hypothesis 3, referring to the relevant literature [50], this study proposes the subsequent mediating effect model:

$$CI_{it} = \partial_0 + \partial_1 shrink_{it} + \partial_2 M_{it} + \gamma control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (10)$$

$$M_{it} = \alpha_0 + \alpha_1 shrink_{it} + \gamma control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (11)$$

where ∂_0 and α_0 are constant terms in the model, ∂_i and α_i are regression coefficients of the variables in the model, M denotes the intermediary variable.

Finally, through a series of diagnostic examinations—including Moran's I statistic, Lagrange Multiplier assessments, and robust variants thereof, complemented by Wald and Likelihood Ratio tests, the article ultimately uses the spatial Durbin model as an analytical tool for spatial spillover effects. The model is constructed as follows:

$$CI_{it} = \beta_0 + \ell WCI_{it} + \delta shrink_{it} + \gamma control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (12)$$

In Equation (12), W is the spatial weights matrix, we adopt the spatial economic distance matrix (constructed based on the reciprocal of the differences in per capita GDP among prefecture-level cities and above in various regions) and the spatial geographic distance matrix (constructed by applying the inverse of the straight-line distance of each prefectural city and above) for the regression; ℓ is the spatial autoregressive coefficient, which measures the degree of spatial autocorrelation of the carbon emission intensity; and δ is the spatial lag coefficient, which calculates the spatial effect of the urban contraction indicator.

3.4. Data Source and Descriptive

Municipal districts are the core areas of each city, which represent cities in the physical sense, so this paper selects the panel data of 278 municipal districts of prefectural-level and above cities in China from 2012 to 2021 (to ensure the availability of data, cities with seriously missing samples were excluded; to ensure the scientific nature and comparability of data, the four cities of Beijing, Tianjin, Shanghai, and Chongqing were excluded), which can more accurately reflect the phenomenon of contraction in Chinese cities. The data for each indicator come from China Statistical Yearbook, China Urban Statistical Year-

book, China Urban Construction Statistical Yearbook, and other statistical yearbooks at various levels.

Table 2 presents descriptive statistics for all variables.

Table 2. Descriptive statistics of variables.

Variable	Mean	Std	Min	Max	Obs
CI	7.626	10.254	0.166	147.015	2780
SK	−0.054	0.133	−1.351	0.172	2780
Hc	0.052	0.058	2.50×10^{-7}	1.086	2780
UIS	1.084	0.573	0.130	5.350	2780
Ln Econ	11.006	0.551	8.327	15.675	2780
Ln People	4.683	0.738	2.715	6.920	2780
Urban	0.090	0.167	0.001	7.222	2780
Indus	45.247	11.689	9.490	87.960	2780
Govern	0.184	0.121	0.010	2.702	2780
Consumption	0.463	0.186	0.000	4.841	2780
Ln Labor	12.140	0.977	7.712	16.208	2780

4. Results and Discussion

4.1. Analysis of the Results of Carbon Emission Intensity Measurement in Shrinking Cities and Growing Cities

According to the above discussion, when $(UDI_n - UDI_{2011} < 0)$, cities experience contraction phenomena. Therefore, when $(UDI_n - UDI_{2011} < 0)$, it is defined as a shrinking city, when $(UDI_n - UDI_{2011} \geq 0)$, it is defined as a growing city. Based on this classification standard, 278 Chinese cities at the prefecture level or higher in 2012, 2015, 2018, and 2021 were categorized into shrinking cities and growing cities. The average carbon emission intensity of shrinking cities and growing cities each year was then computed, and the results are shown in Figure 1.

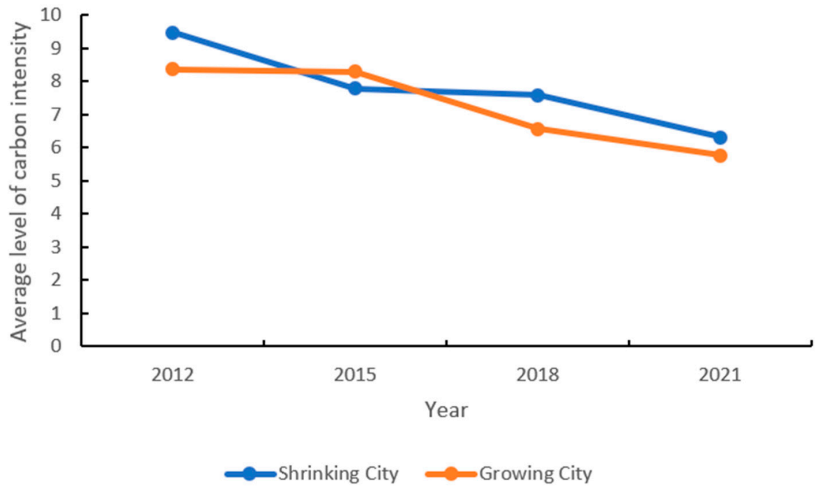


Figure 1. Total carbon emission intensity development trends of shrinking and growing cities in China, 2012–2021.

As can be seen from Figure 1, first of all, regardless of whether it is a contracting city or a growing city, the carbon emission intensity has generally shown a downward trend. This indicates that China has actively responded to global climate change, adhered to the development path of ecological sustainability, continuously strengthened environmental supervision, and attached importance to adjusting the energy structure. The growth rate of carbon emissions has slowed down. Secondly, from 2012 to 2021, in general, compared with the average carbon emission intensity of growth-oriented cities, that of shrinking cities is

even greater. This gap is due to the fact that shrinking cities are mainly resource-dependent urban cities and economically disadvantaged cities. They mainly develop heavy industries with high polluting emissions, and due to the underdeveloped economy, the investment in technological research and development is insufficient, the production processes are backward, and the energy utilization efficiency is low.

4.2. Benchmark Regression

To enhance model robustness, this study analyzes how urban shrinkage affects carbon emission intensity across varied model settings.

As Table 3 demonstrates, the regression analysis reveals statistically significant positive coefficients for all urban decline indicators, which indicates a significant positive correlation between urban shrinkage and carbon emission intensity. In a related study, Liu et al. [51] demonstrated that urban decline contributes to elevated carbon outputs, with contracting urban areas exhibiting significantly poorer energy performance compared to their expanding counterparts. These findings align closely with the outcomes of the current study. Hypothesis 1 is verified.

Table 3. Baseline regression results.

Variable	CI	CI
SK	4.446 ***	4.020 ***
	(5.58)	(6.13)
Ln Econ		−2.586 ***
		(−13.23)
Ln People		−4.024 ***
		(−15.25)
Urban		0.455 *
		(1.65)
Indus		−0.069 ***
		(−7.51)
Govern		5.038 ***
		(9.25)
Consumption		4.428 ***
		(12.79)
Ln Labor		−1.159 ***
		(−7.01)
_cons	3.310 ***	70.306 ***
	(4.19)	(22.26)
Time fixed effect	Yes	Yes
Individual fixed effect	Yes	Yes
N	2780	2780
R^2	0.949	0.967

Note: *** $p < 0.01$ and * $p < 0.1$.

The analysis of control variables reveals that the economic development level, population size, industrial structure, and labor force level are significantly negatively correlated with carbon emission intensity. The concurrent advancement of economic prosperity, demographic concentration, sectoral upgrading, and human capital accumulation creates favorable conditions for lowering carbon outputs through enhanced financial resources, skilled workforce availability, and technological innovation [52,53]. The urbanization rate, government intervention, and the social consumption level all stimulate an increase in carbon intensity. The rapid progression of urban development has precipitated escalating requirements for diverse infrastructural systems and communal amenities, consequently driving heightened energy utilization and associated greenhouse gas discharges [54]. Before an effective market mechanism for emission reduction has been established, excessive government regulation of carbon

emission behaviors will promote the increase in carbon emissions to a certain extent [55]. As the income level of the residents increases, the consumption structure shifts to prefer consuming high-end consumer goods, and the tertiary industry is gradually flourishing, forcing the secondary industry to continuously transform and upgrade, with a consequent increase in energy consumption [56].

4.3. Robustness Tests

4.3.1. Replacing Core Explanatory Variables

The article draws on the idea of Morduch [11] to measure the contraction degree by the change in the number of household population at the end of the year in the municipal district and replaces the urban contraction indicator to conduct the regression, and Table 4 regression (1) shows the regression results. Urban shrinkage still shows a significant positive relationship with carbon intensity, verifying the previous conclusion.

Table 4. Robustness test results.

Variable	(1)	(2)	(3)	(4)	(5)
IV				−0.002 ***	
				(−4.68)	
SK	2.668 ***	7.171 ***			27.867 **
	(4.27)	(2.61)			(2.22)
L. SK			4.710 ***		
			(8.12)		
Control variable	Yes	Yes	Yes	Yes	Yes
_cons	57.939 ***	52.369 ***	67.201 ***	0.121 *	76.266 ***
	(16.05)	(14.94)	(24.18)	(1.69)	(8.46)
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
N	2780	1946	2502	2780	2780
R^2	0.967	0.980	0.452	0.095	0.398
F-statistics value				21.922	

Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

4.3.2. Shortening the Time Window

The original time window is 2012–2021. In order to verify whether the model is robust, the time window is changed to 2015–2021 to conduct regression analysis again. The specific results are shown in Table 4 regression (2). The urban contraction regression coefficient is still significantly positive, again verifying the above conclusion.

4.3.3. Core Explanatory Variables Lagged

The principal independent variable, measuring urban decline, was temporally lagged by one observational interval, with the corresponding empirical outcomes presented in the third regression model of Table 4. The analysis confirms a persistent positive association between urban contraction and carbon intensity, thereby reinforcing the reliability of the aforementioned findings.

4.3.4. Instrumental Variable

Referring to the research ideas of the related literature [57], this study employs the municipal district's natural demographic growth rate as an instrumental variable (IV), applying the two-stage least squares estimation approach (2SLS) for model estimation. The natural population growth rate reflects the natural increase or decrease in population and is related to population size, but it has no direct connection with the carbon emission intensity of cities. Therefore, it is feasible to select the natural population growth rate. Table 4 regression (4) and regression (5) show the relevant results.

As known from Table 4, the first-stage F-value exceeds 10, confirming the instrumental variable's correlation with the endogenous explanatory variable urban contraction level, i.e., there is no weak instrumental quantity problem. Moreover, the natural population growth rate is significantly negatively correlated with the level of urban shrinkage, i.e., the lower the natural population growth rate is, the higher the level of urban shrinkage is. The second-stage estimation outcomes demonstrate a statistically significant positive association between urban contraction and the dependent variable when employing instrumental variable analysis, and the empirical results remain robust.

4.4. Impact Mechanism Test

In order to further explore the mechanism of urban contraction on carbon emission intensity, we adopt the stepwise regression method and test the mechanism based on Equations (9)–(11). The results are shown in Table 5.

Table 5. Results of the mediation effect test.

Explanatory Variable	Hc	CI	UIS	CI	CI
Hc		−12.972 ***			−13.038 ***
		(−8.85)			(−8.90)
UIS				−0.510 ***	−0.537 ***
				(−2.63)	(−2.81)
SK	−0.020 **	3.761 ***	−0.127 *	3.955 ***	3.692 ***
	(−2.26)	(5.82)	(−1.87)	(6.03)	(5.71)
Ln Econ	0.004 *	−2.529 ***	−0.043 **	−2.608 ***	−2.552 ***
	(1.66)	(−13.13)	(−2.12)	(−13.35)	(−13.26)
Ln People	−0.045 ***	−4.611 ***	−0.071 ***	−4.060 ***	−4.652 ***
	(−12.74)	(−17.20)	(−2.60)	(−15.39)	(−17.35)
Urban	0.002	0.477 *	0.026	0.469 *	0.491 *
	(0.45)	(1.76)	(0.91)	(1.70)	(1.81)
Indus	−0.000	−0.070 ***	−0.023 ***	−0.080 ***	−0.082 ***
	(−0.82)	(−7.77)	(−24.27)	(−7.92)	(−8.23)
Govern	−0.002	5.016 ***	0.085	5.081 ***	5.062 ***
	(−0.23)	(9.35)	(1.50)	(9.33)	(9.44)
Consumption	0.008 *	4.530 ***	−0.029	4.413 ***	4.515 ***
	(1.69)	(13.28)	(−0.81)	(12.76)	(13.25)
Ln Labor	0.006 ***	−1.076 ***	0.006	−1.156 ***	−1.073 ***
	(2.86)	(−6.59)	(0.38)	(−6.99)	(−6.58)
cons	0.231 ***	73.301 ***	2.661 ***	71.662 ***	74.744 ***
	(5.43)	(23.43)	(8.14)	(22.42)	(23.61)
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
N	2780	2780	2780	2780	2780
R^2	0.810	0.968	0.887	0.967	0.968

Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

Model (1) shows that the estimated coefficient for urban decline is negative and statistically significant, suggesting that urban contraction exerts a substantial adverse effect on regional human capital accumulation. Model (2) shows that even after accounting for the mediating role of human capital, a robust positive association persists between urban decline and carbon emissions, and human capital development demonstrates a significant mitigating influence on emission intensity. These results collectively indicate that urban shrinkage indirectly elevates carbon emissions through its negative impact on human capital formation, thereby providing empirical support for Hypothesis 2. Similarly, according to the test results of model (3) and model (4), by impeding the upgrading of industrial structure, urban shrinkage will result in a rise in the intensity of carbon emissions. Hypothesis 3 has been verified. Model (5) incorporates both mediating pathways concurrently. The analysis reveals a statistically

significant positive effect of urban decline on carbon intensity, thereby reaffirming the dual mediating mechanisms through which urban contraction influences emission intensity.

4.5. Heterogeneity Analysis

4.5.1. Analysis of Regional Differences

To explore the regional heterogeneity, this paper conducts regression analyses of the impact of urban shrinkage on carbon emission intensity in the East, Central, and West regions, respectively, as can be seen in Table 6. From the coefficients, the extent to which urban shrinkage affects carbon intensity is greatest in the western region, followed by the central region, and finally, the eastern region.

The eastern region has unique geographical advantage, good business environment, national policy support, and other development conditions. It not only attracts a variety of resources from other regions of the country but also continuously introduces foreign talent and a variety of technological resources, and the level of urban contraction is relatively low. Moreover, the eastern region mainly develops tertiary industry, which is less polluting to the environment, and invests much capital, technology, and talent in environmental management, pollution reduction, and carbon reduction. Therefore, the impact of urban contraction problems, such as population shrinkage and industry transfer, on their carbon emission intensity is relatively small. Most cities in central and western China are resource-dependent, with economies centered on heavy industry. However, mineral resources are always limited and will be exhausted, and the continuous adjustment of the domestic industrial structure forces these regions to vigorously develop the emerging industry, and the value added of industrial products is reduced. Driven by interests, the labor force will gradually flow to developed areas, and the phenomenon of urban contraction is gradually serious. Due to the characteristics of the western region, such as large span and wide area, resulting in small population density, it is difficult to play the population and industrial agglomeration effect and scale effect to reduce carbon emissions, while the flow of high-quality labor to the eastern region, the enterprise's green technology innovation, production process update lack of financial, technical, and human resources support, backward industries exacerbate the city's carbon emissions and inhibit green development. Furthermore, China's industrial migration exhibits the "pollution refuge" effect. Enterprises in the eastern regions with high environmental regulatory standards will transfer underdeveloped industries to central and western China, where environmental regulation is relatively lenient, in order to reduce environmental protection costs. Some areas in the central and western regions have relaxed environmental regulations due to the urgent pursuit of economic growth targets and have become "pollution havens" for the developed regions in China. For instance, chemical enterprises in provinces such as Jiangsu and Zhejiang have relocated to regions like Ningxia and Inner Mongolia due to the pressure of environmental regulation.

4.5.2. Analysis of Urban Type Differences

Resource-dependent cities have contributed greatly to China's rapid economic development. However, as the industrial structure keeps adjusting and optimizing and the economy enters a stage of high-quality development, resources no longer have advantages for development. At the same time, the limited resources are facing the situation of depletion in development. These may trigger unemployment waves, and resource-based cities will fall into the double predicament of economic development and population loss. Therefore, it is necessary to consider the impact of the contraction of different types of cities on carbon emission intensity. This study, based on the "Notice of the State Council on Issuing the National Sustainable Development Plan for Resource-Based Cities (2013–2020)", divides the studied cities into resource-based cities and non-resource-based cities.

As you can see in columns (4) and (5) of Table 6, the impact of urban contraction on carbon emission intensity is more significant in resource-based cities due to the fact that the industrial structure of resource-based cities is single and their economic development is highly dependent on resources such as oil and minerals. In the context of population reduction caused by urban contraction, due to their strong resource dependence, it is difficult to transform the industry composition and activate the dynamics of urban economic development. In contrast, non-resource-based cities have diverse economic activities. When urban contraction occurs, they can promptly adjust the original industrial structure and complete economic transformation.

Table 6. Heterogeneity analysis results.

Variable	Eastern Region CI (1)	Central Region CI (2)	Western Region CI (3)	Resource-Based City CI (4)	Non-Resource-Based City CI (5)
SK	1.227 *	4.982 ***	7.175 ***	9.660 ***	2.626 ***
	(1.76)	(3.40)	(4.24)	(4.54)	(4.32)
Ln Econ	−2.588 ***	−2.523 ***	−2.015 ***	−1.793 ***	−3.267 ***
	(−8.03)	(−8.04)	(−5.34)	(−5.98)	(−12.83)
Ln People	−5.193 ***	−2.367 ***	−5.765 ***	−6.070 ***	−3.254 ***
	(−14.64)	(−5.50)	(−8.64)	(−12.18)	(−11.50)
Urban	−1.034	0.561 **	−1.182	−3.727 ***	0.585 **
	(−1.21)	(2.03)	(−0.31)	(−2.58)	(2.47)
Indus	−0.065 ***	−0.101 ***	−0.088 ***	−0.094 ***	−0.058 ***
	(−4.54)	(−6.59)	(−4.90)	(−5.82)	(−5.60)
Govern	0.629	5.122 ***	5.000 ***	10.728 ***	2.805 ***
	(0.43)	(8.19)	(2.88)	(9.13)	(5.19)
Consumption	4.697 ***	4.151 ***	4.586 ***	2.228 ***	5.301 ***
	(7.65)	(6.28)	(5.99)	(2.68)	(15.95)
Ln Labor	−0.667 **	−1.729 ***	−0.797 ***	−1.766 ***	−0.843 ***
	(−2.35)	(−5.71)	(−2.83)	(−5.70)	(−4.82)
_cons	70.668 ***	69.441 ***	63.970 ***	85.439 ***	68.206 ***
	(14.59)	(13.87)	(10.18)	(15.90)	(18.18)
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
N	960	1000	820	1130	1650
R^2	0.925	0.983	0.949	0.975	0.953

Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

4.6. Additional Analysis

4.6.1. Model Selection

As illustrated in Table 7, the Moran Index of urban carbon emission intensity under both the spatial economic distance matrix and spatial geographic distance matrix is positively significant, indicating the existence of spatial autocorrelation of urban carbon emission intensity.

Table 7. The Moran Index results.

Year	Moran's	
	w1	w2
2012	0.156 *** (5.947)	0.024 *** (6.005)
2013	0.158 *** (5.889)	0.028 *** (6.781)
2014	0.143 *** (5.506)	0.033 *** (8.070)
2015	0.148 *** (5.491)	0.037 *** (8.641)
2016	0.150 *** (5.576)	0.041 *** (9.442)
2017	0.152 *** (5.594)	0.047 *** (10.653)
2018	0.137 *** (5.257)	0.045 *** (10.602)
2019	0.142 *** (5.463)	0.064 *** (14.718)
2020	0.129 *** (4.906)	0.066 *** (15.144)
2021	0.127 *** (4.866)	0.072 *** (16.357)

Note: *** $p < 0.01$.

As can be seen from Table 8, under the two spatial weight matrices, after a series of tests, the results show that the SDM model is better than the SEM model and the SAR model, so this paper finally adopts the spatial Durbin of the individual fixed-effects model for the analysis.

Table 8. Spatial measurement model experimental results.

Test	w1		w2	
	Statistic	***p*-Value**	**Statistic**	***p*-Value**
LM (error)	19.165	0.000	32.073	0.000
Robust-LM (error)	26.258	0.000	6.866	0.009
LM (lag)	2.524	0.112	34.330	0.000
Robust-LM (lag)	9.617	0.002	9.123	0.003
LR test (sar-sdm)	23.960	0.002	17.250	0.028
LR test (sem-sdm)	22.690	0.004	34.270	0.000
Wald test (sar-sdm)	24.140	0.002	17.030	0.030
Wald test (sem-sdm)	22.700	0.004	33.280	0.000
Hausman	−16.710	-	−2.700	-
LR both ind test	14.650	0.145	8.750	0.556
LR both time test	7326.710	0.000	7285.360	0.000

4.6.2. Spatial Durbin Regression Results

Table 9 shows that, at the 1% level, the carbon emission intensity's ρ value is significantly positive, which again indicates the existence of a positive spatial correlation, implying that after urban shrinkage affects the carbon emission intensity of the city, the carbon emission intensity of the city also affects each other spatially. The spatial Durbin model (SDM) reveals that urban shrinkage significantly influences carbon emission intensity through spatial spillover effects. Among them, the indirect effect is the influence of urban contraction on carbon emission intensity in neighboring regions. As can be seen from the table, both in the spatial economic distance matrix and the spatial geographical distance matrix, urban shrinkage substantially lowers nearby cities' carbon emission intensity. Hypothesis 4 has been verified. Neighboring cities accelerate the outward flow of population, capital, and other factors in shrinking cities due to geographic convenience, policy guidance, improved transportation infrastructure, etc. The economies of scale and resource sharing brought about by population agglomeration in the neighboring cities exert a carbon emission reduction effect, which reduces the intensity of carbon emissions in the cities. Furthermore, neighboring cities are also the primary destinations for the industrial transfer of contracting cities. Contracting cities may transfer traditional high-energy-consuming industries to neighboring cities to optimize their industrial structure and enhance economic vitality. The receiving areas become "pollution refuges" for contracting cities, leading to an increase in carbon emissions. However, based on the results of this study, the population and industrial transfer brought by contracting cities have not exacerbated the carbon emissions of the receiving areas. This is mainly because the establishment of the "pollution refuge hypothesis" cannot be generalized. Due to the strict environmental regulatory standards set by the receiving areas, only low-input, low-consumption, and high-value-added enterprises are allowed to enter, or traditional high-energy-consuming industries are forced to upgrade [58], such as replacing coal-fired power with clean energy, which helps improve the local environment. At the same time, when neighboring cities receive industrial transfer, they will optimize the production network through spatial reorganization, enhancing the collaborative efficiency of the upstream, midstream, and downstream industrial chains. For example, relying on multi-center layouts to shorten the transportation distance of product

components and reduce carbon emissions in the logistics process, thereby reducing the carbon emission intensity of neighboring cities.

Table 9. Spatial Durbin model effect decomposition results.

Variable	w1	w2
SK	3.342 ***	3.811 ***
	(4.92)	(6.11)
Wx	−4.020 ***	−5.220 ***
	(−4.96)	(−6.16)
Control variable	Yes	Yes
Spatial autoregression coefficient rho	0.288 ***	0.621 ***
	(8.10)	(6.58)
Spatial lag coefficient δ	3.346 ***	3.369 ***
	(37.06)	(37.21)
Direct effect	3.240 ***	3.808 ***
	(4.80)	(5.97)
Indirect effect	−4.154 ***	−7.617 ***
	(−4.70)	(−4.03)
Aggregate effect	−0.915 *	−3.809 **
	(−1.65)	(−2.10)
R^2	0.413	0.424
N	2780	2780
Individual fixed effect	Yes	Yes

Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

5. Conclusions and Policy Recommendations

5.1. Conclusions

This study examines data from 278 Chinese cities at the prefecture level or higher between 2012 and 2021 and employs a two-way fixed-effects model, along with mediation analysis and spatial econometric techniques, to conduct a thorough empirical investigation. The findings can be summarized as follows: (1) The baseline regression results show that there is a positive correlation between urban shrinkage and carbon emission intensity, which still holds after a series of robustness tests. (2) The analysis of mediating mechanisms reveals that a city's human capital level and the upgrading of industrial structure serve as the primary channels through which urban decline influences carbon emission intensity. (3) The heterogeneity test shows that there are differences in the effects of urban shrinkage on carbon emission intensity in different regions and types of cities. (4) The analysis of spatial spillover effects reveals that urban contraction could significantly lower the carbon emission intensity of nearby cities through the overall socio-economic changes brought about by it.

5.2. Policy Recommendations

(1) Correctly treat the phenomenon of urban shrinkage and take measures to actively respond to it so as to realize the transformation of cities into smart shrinking cities. Shrinking cities are facing the double pressure of population loss and increased carbon emission intensity, and if they are left unchecked or expanded, they will only fall into a state of decline. First of all, the government should change the urban development idea of "the larger the urban space, the more conducive to urban development", reasonably regulate the urban space, prevent the urban population from becoming more and more dispersed, and guide the city toward compact and smart development; reasonably utilize the unused land and buildings, improve the city's ecological environment by means of parks and green spaces, and improve the livability quality of the city. Secondly, it is necessary to guide the agglomeration of population and

resources to give full play to the carbon emission reduction effect brought about by economies of scale, resource sharing, and knowledge spillover. For example, taking new urbanization as an opportunity, relaxing the restrictions on urban and rural population mobility, and guiding rural residents to cluster in urban core areas [59]. Finally, the accumulation of human capital should be emphasized to improve the city's innovation capacity. The first step is to cultivate talents and increase the stock of human capital, such as increasing the investment in higher education and vocational education and formulating talent cultivation policies according to local conditions; the next step is to attract excellent talents and improve the quality of human capital, such as improving the treatment of talents, improving the basic public service system, and providing a suitable working and living environment to attract the inflow of high-quality talents and other measures.

(2) For the shrinking cities in the East, deepening the adjustment of industrial structure is a key move, and the necessity of its continuous strengthening adjustment should not be ignored. For example, they should actively encourage technological innovation in high-tech fields such as artificial intelligence and biotechnology to promote the upgrading of the city's industrial structure, and they should promote the development of service industries such as the financial industry, education, and medical care, so as to enhance the competitiveness of the city and provide more employment opportunities. In response to the challenges posed by urban contraction in the central and western regions to carbon emissions, the optimization and upgrading of their industrial structure is even more important. The first step is to promote the development of the industrial structure in the direction of higher-end, greener, and more diversified, such as expanding non-resource-based industries, preventing the city from falling into development difficulties when resources are exhausted [60]; developing the tourism industry by utilizing the local characteristic resources, forming local pillar industries, and bringing new economic growth points to the region; and transforming the mode of agricultural development, vigorously developing eco-agriculture, and consolidating the important position of agriculture in the western region. To this end, the government should introduce relevant policies such as tax incentives and enterprise financial support policies to support, so as to encourage enterprises to invest in emerging industries, promoting industrial agglomeration and the formation of new industrial clusters. Secondly, it is necessary to guide the spatial agglomeration of population and industries in shrinking areas so as to enhance economic vitality and the efficiency of resource allocation. By focusing on major national strategic arrangements, the construction of urban circles will play a radiation-driven role in neighboring regions, forming the "attracting, converging and stabilizing" effect of the central city on the regional population and other development factors. Finally, a large amount of unused vacant land will be transformed into ecological space such as creating large parks, forming ecological landscapes, and strengthening the attraction of the population in the surrounding areas [61]. This not only optimizes the spatial layout of the city but also maintains urban vitality and creates favorable conditions for the city to attract population.

(3) Firstly, we should give priority to the development of transportation network, improve the overall connectivity of the region, build a perfect highway, railroad, aviation and other transportation networks, and strengthen the exchanges and cooperation between cities. Secondly, the government can break through the limitations of administrative regions and establish cross-regional management institutions to coordinate the sharing of infrastructure and resources within the region, and coordinate the balanced development of cities within the region to prevent the phenomenon of urban contraction from occurring or spreading. Thirdly, communication and interaction between cities should be strengthened, and some of the functions of central cities should be transferred to neighboring cities in order to realize the common development and sharing of transportation, resources,

industries, and talents between cities, so as to prevent the emergence of problems such as the loss of talents and the transfer of industries.

5.3. Limitations and Future Research Directions

Firstly, due to the lack of data, the data samples used in this research are limited to 278 prefecture-level and above cities in China. Although these cities have certain representativeness, the wide applicability of the results remains controversial. In future research, the data sources should be further expanded to include more prefecture-level and county-level cities. Secondly, urban shrinkage is a complex social phenomenon, and the criteria for measuring it are diverse and complex, making it difficult to measure comprehensively and accurately. In future research, incorporating more up-to-date datasets or other indicators for measuring urban shrinkage, such as changes in land use or economic productivity, would be beneficial to the study.

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References

1. Gao, P.; Yue, S.; Chen, H. Carbon emission efficiency of China's industry sectors: From the perspective of embodied carbon emissions. *J. Clean. Prod.* **2021**, *283*, 124655. [CrossRef]
2. Shan, Y.; Guan, D.; Hubacek, K.; Zheng, B.; Davis, S.J.; Jia, L.; Liu, J.; Liu, Z.; Fromer, N.; Mi, Z. City-level climate change mitigation in China. *Sci. Adv.* **2018**, *4*, eaaq0390. [CrossRef]
3. Wiechmann, T. Errors expected—Aligning urban strategy with demographic uncertainty in shrinking cities. *Int. Plan. Stud.* **2008**, *13*, 431–446. [CrossRef]
4. Wiechmann, T.; Pallagst, K.M. Urban shrinkage in Germany and the USA: A comparison of transformation patterns and local strategies. *Int. J. Urban Reg. Res.* **2012**, *36*, 261–280. [CrossRef]
5. Yang, Z.; Dunford, M. City shrinkage in China: Scalar processes of urban and hukou population losses. *Reg. Stud.* **2018**, *52*, 1111–1121. [CrossRef]
6. Zhang, Y.; Fu, Y.; Kong, X.; Zhang, F. Prefecture-level city shrinkage on the regional dimension in China: Spatiotemporal change and internal relations. *Sust. Cities Soc.* **2019**, *47*, 101490. [CrossRef]
7. Li, H.; Mykhnenko, V. Urban shrinkage with Chinese characteristics. *Geogr. J.* **2018**, *184*, 398–412. [CrossRef]
8. Hu, X.; Yang, C. Building a role model for rust belt cities? Fuxin's economic revitalization in question. *Cities* **2018**, *72*, 245–251. [CrossRef]
9. He, S.Y.; Lee, J.; Zhou, T.; Wu, D. Shrinking cities and resource-based economy: The economic restructuring in China's mining cities. *Cities* **2017**, *60*, 75–83. [CrossRef]
10. Fernandez, B.; Hartt, M. Growing shrinking cities. *Reg. Stud.* **2022**, *56*, 1308–1319. [CrossRef]
11. Murdoch III, J. Specialized vs. diversified: The role of neighborhood economies in shrinking cities. *Cities* **2018**, *75*, 30–37. [CrossRef]
12. Saraiva, M.; Roebeling, P.; Sousa, S.; Teotónio, C.; Palla, A.; Gnecco, I. Dimensions of shrinkage: Evaluating the socio-economic consequences of population decline in two medium-sized cities in Europe, using the SULD decision support tool. *Envion. Plan. B-Urban Anal. City Sci.* **2017**, *44*, 1122–1144. [CrossRef]
13. Rink, D.; Couch, C.; Haase, A.; Krzysztofik, R.; Nadolu, B.; Rumpel, P. The governance of urban shrinkage in cities of post-socialist Europe: Policies, strategies and actors. *Urban Res. Pract.* **2014**, *7*, 258–277. [CrossRef]

14. Peng, W.; Fan, Z.; Duan, J.; Gao, W.; Wang, R.; Liu, N.; Li, Y.; Hua, S. Assessment of interactions between influencing factors on city shrinkage based on geographical detector: A case study in Kitakyushu, Japan. *Cities* **2022**, *131*, 103958. [CrossRef]
15. Großmann, K.; Bontje, M.; Haase, A.; Mykhnenko, V. Shrinking cities: Notes for the further research agenda. *Cities* **2013**, *35*, 221–225. [CrossRef]
16. Martinez-Fernandez, C.; Audirac, I.; Fol, S.; Cunningham-Sabot, E. Shrinking cities: Urban challenges of globalization. *Int. J. Urban Reg. Res.* **2012**, *36*, 213–225. [CrossRef]
17. You, H.; Yang, J.; Xue, B.; Xiao, X.; Xia, J.; Jin, C.; Li, X. Spatial evolution of population change in Northeast China during 1992–2018. *Sci. Total Environ.* **2021**, *776*, 146023. [CrossRef]
18. Sun, J.; Zhou, T. Urban shrinkage and eco-efficiency: The mediating effects of industry, innovation and land-use. *Environ. Impact Assess. Rev.* **2023**, *98*, 106921. [CrossRef]
19. Yang, Y.; Wu, J.; Wang, Y.; Huang, Q.; He, C. Quantifying spatiotemporal patterns of shrinking cities in urbanizing China: A novel approach based on time-series nighttime light data. *Cities* **2021**, *118*, 103346. [CrossRef]
20. Sun, Y.; Wang, Y.; Zhou, X.; Chen, W. Are shrinking populations stifling urban resilience? Evidence from 111 resource-based cities in China. *Cities* **2023**, *141*, 104458. [CrossRef]
21. Wang, Y.; Li, X.; Yao, X.; Li, S.; Liu, Y. Intercity population migration conditioned by city industry structures. *Ann. Am. Assoc. Geogr.* **2022**, *112*, 1441–1460. [CrossRef]
22. Bernt, M. The limits of shrinkage: Conceptual pitfalls and alternatives in the discussion of urban population loss. *Int. J. Urban Reg. Res.* **2016**, *40*, 441–450. [CrossRef]
23. Jarzebski, M.P.; Elmqvist, T.; Gasparatos, A.; Fukushi, K.; Eckersten, S.; Haase, D.; Goodness, J.; Khoshkar, S.; Saito, O.; Takeuchi, K. Ageing and population shrinking: Implications for sustainability in the urban century. *NPJ Urban Sustain.* **2021**, *1*, 17. [CrossRef]
24. Du, M.; Antunes, J.; Wanke, P.; Chen, Z. Ecological efficiency assessment under the construction of low-carbon city: A perspective of green technology innovation. *J. Environ. Plan. Manag.* **2022**, *65*, 1727–1752. [CrossRef]
25. Tong, X.; Guo, S.; Duan, H.; Duan, Z.; Gao, C.; Chen, W. Carbon-emission characteristics and influencing factors in growing and shrinking cities: Evidence from 280 Chinese cities. *Int. J. Environ. Res. Public Health* **2022**, *19*, 2120. [CrossRef]
26. Xiao, H.; Duan, Z.; Zhou, Y.; Zhang, N.; Shan, Y.; Lin, X.; Liu, G. CO_2 emission patterns in shrinking and growing cities: A case study of Northeast China and the Yangtze River Delta. *Appl. Energy* **2019**, *251*, 113384. [CrossRef]
27. Yang, S.; Yang, X.; Gao, X.; Zhang, J. Spatial and temporal distribution characteristics of carbon emissions and their drivers in shrinking cities in China: Empirical evidence based on the NPP/VIIRS nighttime lighting index. *J. Environ. Manag.* **2022**, *322*, 116082. [CrossRef]
28. He, X.; Gao, W.; Guan, D.; Zhou, L. Nonlinear mechanisms of CO_2 emissions in growing and shrinking cities: An empirical study on integrated effects of aging and industrial structure in Japan. *J. Clean. Prod.* **2024**, *462*, 142665. [CrossRef]
29. Meng, X.; Long, Y. Shrinking cities in China: Evidence from the latest two population censuses 2010–2020. *Environ. Plan. A Econ. Space* **2022**, *54*, 449–453. [CrossRef]
30. Liu, Y.J.; Yang, M.R.; Cui, J.H. Urbanization, economic agglomeration and economic growth. *Heliyon* **2024**, *10*, e23772. [CrossRef]
31. Haase, A.; Bernt, M.; Großmann, K.; Mykhnenko, V.; Rink, D. Varieties of shrinkage in European cities. *Eur. Urban Reg. Stud.* **2016**, *23*, 86–102. [CrossRef]
32. Wang, N.; Zhu, Y.; Yang, T. The impact of transportation infrastructure and industrial agglomeration on energy efficiency: Evidence from China's industrial sectors. *J. Clean. Prod.* **2020**, *244*, 118708. [CrossRef]
33. Yan, Y.; Huang, J. The role of population agglomeration played in China's carbon intensity: A city-level analysis. *Energy Econ.* **2022**, *114*, 106276. [CrossRef]
34. Liu, J.; Cheng, Z.; Zhang, H. Does industrial agglomeration promote the increase of energy efficiency in China? *J. Clean. Prod.* **2017**, *164*, 30–37. [CrossRef]
35. Zhong, X.F.; Lu, Y.; Zhong, Z.Q. Did regional coordinated development policy mitigate carbon emissions? Evidence from the Beijing-Tianjin-Hebei region in China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 108992–109006. [CrossRef]
36. Li, Y.; Chen, Z. Does transportation infrastructure accelerate factor outflow from shrinking cities? An evidence from China. *Transp. Policy* **2023**, *134*, 180–190. [CrossRef]
37. Wang, N.; Yu, H.; Shu, Y.; Chen, Z.; Li, T. Can green patents reduce carbon emission intensity?—An empirical analysis based on China's experience. *Front. Environ. Sci.* **2022**, *10*, 1084977. [CrossRef]
38. Cong, J.; Liu, X.; Zhao, X. Boundary definition of urban carbon emission accounting and its measurement method. *China Popul. Resour. Environ.* **2014**, *24*, 19–26.
39. Luo, Y.; Fang, S.; Wu, H.; Zhou, X.; He, Z.; Gao, L. Spatial and temporal evolution of habitat quality and its shrinkage effect in shrinking cities: Evidence from Northeast China. *Ecol. Indic.* **2024**, *161*, 111919. [CrossRef]
40. Heim LaFrombois, M.E.; Park, Y.; Yurcaba, D. How US shrinking cities plan for change: Comparing population projections and planning strategies in depopulating US cities. *J. Plan. Educ. Res.* **2023**, *43*, 81–93. [CrossRef]

41. He, X.; Guan, D.; Zhou, L.; Zhang, Y.; Gao, W.; Sun, L.; Huang, D.; Li, Z.; Cao, J.; Su, X. Quantifying spatiotemporal patterns and influencing factors of urban shrinkage in China within a multidimensional framework: A case study of the Yangtze River Economic Belt. *Sust. Cities Soc.* **2023**, *91*, 104452. [CrossRef]
42. Zhang, X.; Zhang, Q.; Zhang, X.; Gu, R. Spatial-temporal evolution pattern of multidimensional urban shrinkage in China and its impact on urban form. *Appl. Geogr.* **2023**, *159*, 103062. [CrossRef]
43. Liu, Z.; Liu, S.; Song, Y. Understanding urban shrinkage in China: Developing a multi-dimensional conceptual model and conducting empirical examination from 2000 to 2010. *Habitat Int.* **2020**, *104*, 102256. [CrossRef]
44. Wang, X.; Wang, Y.; Zheng, R.; Wang, J.; Cheng, Y. Impact of human capital on the green economy: Empirical evidence from 30 Chinese provinces. *Environ. Sci. Pollut. Res.* **2023**, *30*, 12785–12797. [CrossRef]
45. Song, M.; Tao, W.; Shen, Z. Improving high-quality development with environmental regulation and industrial structure in China. *J. Clean. Prod.* **2022**, *366*, 132997. [CrossRef]
46. Liu, W.; Zhu, P. The impact of green finance on the intensity and efficiency of carbon emissions: The moderating effect of the digital economy. *Front. Environ. Sci.* **2024**, *12*, 1362932. [CrossRef]
47. Wu, Y.; Xu, H. The Effect of FDI Agglomeration on carbon emission intensity: Evidence from city-level data in China. *Sustainability* **2023**, *15*, 1716. [CrossRef]
48. Liu, J.; Duan, Y.; Zhong, S. Does green innovation suppress carbon emission intensity? New evidence from China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 86722–86743. [CrossRef]
49. Chang, H.; Ding, Q.; Zhao, W.; Hou, N.; Liu, W. The digital economy, industrial structure upgrading, and carbon emission intensity—Empirical evidence from China's provinces. *Energy Strategy Rev.* **2023**, *50*, 101218. [CrossRef]
50. Wang, Z.; Zhu, C. Does urban sprawl lead to carbon emission growth?—Empirical evidence based on the perspective of local land transfer in China. *J. Clean. Prod.* **2024**, *455*, 142319. [CrossRef]
51. Liu, X.; Wang, M.; Qiang, W.; Wu, K.; Wang, X. Urban form, shrinking cities, and residential carbon emissions: Evidence from Chinese city-regions. *Appl. Energy* **2020**, *261*, 114409. [CrossRef]
52. Yu, X.; Wu, Z.; Zheng, H.; Li, M.; Tan, T. How urban agglomeration improve the emission efficiency? A spatial econometric analysis of the Yangtze River Delta urban agglomeration in China. *J. Environ. Manag.* **2020**, *260*, 110061. [CrossRef] [PubMed]
53. Pang, Q.; Zhou, W.; Zhao, T.; Zhang, L. Impact of urbanization and industrial structure on carbon emissions: Evidence from Huaihe River Eco-Economic Zone. *Land* **2021**, *10*, 1130. [CrossRef]
54. Ahmad, M.; Zhao, Z.-Y.; Li, H. Revealing stylized empirical interactions among construction sector, urbanization, energy consumption, economic growth and CO_2 emissions in China. *Sci. Total Environ.* **2019**, *657*, 1085–1098. [CrossRef] [PubMed]
55. Zhang, S.; Li, J.; Jiang, B.; Guo, T. Government intervention, structural transformation, and carbon emissions: Evidence from China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1343. [CrossRef]
56. Li, Q.; Su, Y.; Wang, Y. Study on the Carbon Emission Reduction Effect of China's Commercial Circulation Industry. *Sustainability* **2024**, *16*, 6163. [CrossRef]
57. Lv, X.; Wu, Z.; Sui, Y. Understanding the dynamics of urban shrinkage and the impact on innovation in China: A comprehensive analysis. *J. Knowl. Econ.* **2024**, *2024*, 1–34. [CrossRef]
58. Elliott, R.J.; Zhou, Y. Environmental regulation induced foreign direct investment. *Environ. Resour. Econ.* **2013**, *55*, 141–158. [CrossRef]
59. Zhou, M.; Shao, W.; Jiang, K.; Huang, L. How does economic agglomeration affect carbon emissions at the county level in Liaoning China? *Ecol. Indic.* **2024**, *158*, 111507. [CrossRef]
60. Wang, J.; Yang, Z.; Qian, X. Driving factors of urban shrinkage: Examining the role of local industrial diversity. *Cities* **2020**, *99*, 102646. [CrossRef]
61. Chen, J.; Kinoshita, T.; Li, H.; Luo, S.; Su, D.; Yang, X.; Hu, Y. Toward green equity: An extensive study on urban form and green space equity for shrinking cities. *Sust. Cities Soc.* **2023**, *90*, 104395. [CrossRef]

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