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Coordinated Relationship between Compactness and Land-Use Efficiency in Shrinking Cities: A Case Study of Northeast China

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Abstract: Compact development and efficient land use are effective ways to address the development dilemma and boost the vitality of shrinking cities. Moreover, it is critical to investigate the relationship between compactness and land-use efficiency in order to healthily and sustainably develop shrinking cities. This study developed an analytical framework to study the coordinated interaction between urban compactness and land-use efficiency in the context of city shrinkage. Fifteen typical shrinking cities in Northeast China were taken as an example of the phenomenon and the entropy value method and super-slack-based measure model were used to quantitatively measure the compactness and land-use efficiency. Furthermore, the coordinated development level and the coordinated relationship between the two were explored with the help of the coupled coordination degree model as well as the quadrant diagram method. The results of the study show that: (1) The overall level of compactness of 15 shrinking cities in Northeast China was low and the improvement of land-use efficiency was not obvious, while the differences of compactness and land-use efficiency between shrinking cities were significant. (2) The coordination between compactness and land-use efficiency was limited; however, the overall coordination remained intermediate, with significant spatial differences and a tendency to further expand. The problem of lagged development of land-use efficiency in shrinking cities could be characterized as serious. (3) Economic development and population size promote the coordinated development of urban compactness and land-use efficiency, whereas science and technology development, industrial structure, as well as government regulation inhibited the coordinated development of urban compactness and land-use efficiency.

Keywords: shrinking cities; compactness; land-use efficiency; coordinated relationship; Northeast China

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1. Introduction

As urbanization accelerates, the demand for land for urban development remains high. The rapid expansion of urban land has resulted in various issues such as inefficient land use, traffic congestion, and environmental pollution [1,2]. Urban sprawl and inefficient use of urban land are also problems of shrinking cities characterized by population loss, which is an example of the paradox of population loss and spatial expansion [3,4]. With population loss, economic stagnation, and irrational expansion of land, it is difficult to ensure continuous and sufficient input of labor, capital, and other factors in urban land. This can easily lead to the vacancy of new land and a decline in the efficiency of developed land use. Land problems in shrinking cities are more severe than in growing cities due to the dual pressure of land expansion and population contraction. Furthermore, there are higher demands placed on the intensive and compact use of land. Compact development is regarded as a viable solution to the problems of disorderly sprawl and inefficient land use [5]. The compact layout of urban elements encourages land to meet the demand for development in a way that improves utilization efficiency. Simultaneously, the construction of compact cities can improve the effective output per unit of land through intensive resource allocation, thereby enhancing the efficiency of land use. The healthy development of shrinking cities is inextricably linked to the compactness of urban space and the efficient use of land. The coordinated development of urban compactness and efficient land use has emerged as a critical issue for shrinking cities seeking to eliminate inefficient land use and achieve intensive and efficient development. Therefore, we first constructed an analytical framework for the study of the coordinated interaction between urban compactness and land-use efficiency in the context of shrinkage. Under the guidance of the analytical framework, the coupled coordination degree model and quadrant diagram method were systematically applied to 15 shrinking cities in Northeast China. Furthermore, the mechanisms that influence the coordinated development of urban compactness and land-use efficiency were also explored.

2. Literature Review and Analytical Framework

2.1. Literature Review

The compact city concept advocates for measures such as high-density development, mixed land-use functions, and public transport development. Rather than blindly increasing urban density and limiting the demand for land, compact development is a compact and intensive development pattern based on meeting the needs of urban development and curbing the waste of land resources caused by urban sprawl. The concept gained popularity due to its unique advantages in reducing irrational urban expansion and increasing the efficiency of the use of land resources [6]. The current body of work on compact cities focuses on measuring urban compactness. Compactness represents the most intuitive quantitative reflection of compact urban development [7,8]. At the moment, the main methods of evaluating urban compactness are single-indicator measurements based on urban morphology [9,10], the characterization via population density and mixed land use [11,12], and multi-indicator comprehensive evaluation methods [13,14]. Compact city research also considers the impact of compact development on urban society, ecology, and land. A compact urban form can gather high-quality resources, improving regional innovation capacity [15]. Compact development, on the other hand, is not synchronous with urban efficiency [8] and the urbanization level [16]. According to Liu et al. (2020) and Wang et al. (2017), compactness is negatively correlated to urban carbon emissions [17,18]. Compact and low-carbon cities can improve CO_2 economic efficiency, but over-compactness may reduce its social efficiency [9]. Compact city construction has a positive impact on enhancing the value of land [5], mitigating urban density decline [19], and reducing land consumption per capita [20]. The majority of current research on urban compactness focuses on growing cities, with insufficient attention paid to shrinking cities. The impact of economic, demographic, and land-use changes on the development of urban compactness in shrinking cities is yet to be investigated.

As land is the spatial carrier of urban economic and social activities [21], land-use efficiency is the evaluation of the comprehensive degree of land use in the process of urban development, taking into account economic, social, and environmental factors. Previous studies gradually enriched and improved the methods of measuring land-use efficiency. Using the entropy value method, data envelopment, and consequent frontier analysis, researchers have thoroughly studied the efficiency of urban, industrial, agricultural, and development zone land [22–28]. Furthermore, more attention has been paid to interaction mechanisms of land-use efficiency and systems such as urban spatial development, economic development, and urban ecology. The relationship between urban spatial development and land-use efficiency is most visible in the expansion of urban scale and the impact of various spatial structure patterns on land-use efficiency. The link between urban scale and land-use efficiency is nonlinear and shaped as an inverted U [29]. The irrational expansion of urban scale results in the spatial separation of population, economy, and land, weakening the rational distribution and circulation of urban elements in space [30]. Moreover, it causes the further fragmentation of urban spatial layout, which leads to inefficient land use [31]. Different urban spatial structure patterns also affect land use. Compared with a monocentric one, polycentric urban spatial structure is more likely to cause fragmentation of land use, thus affecting land-use efficiency use [32]. Urban economy and land-use efficiency are inextricably linked. Regional economic integration can promote optimal resource allocation and improve land-use efficiency [33]. Improving land-use efficiency can aid industrial transformation and development [24]. Similarly, increasing industrial structure rationalization has a positive effect on land-use efficiency [34]. The relationship between urban industrial agglomeration and intensive land use is well coordinated [35]. Regarding the relationship between land-use efficiency and urban ecosystem, Dong et al. (2020) discovered that improving land-use efficiency can effectively reduce urban carbon emissions [24]. However, land-use efficiency and ecosystem health development are still not well coordinated [36] and more optimization and improvement are required. Land issues are prevalent in China at all stages of urban development, and cities which are shrinking are experiencing severe land-use problems garnering them more attention [37]. However, existing studies have not sufficiently explored the relationship between compact urban development and intensive land use in shrinking cities.

The coordinated interaction of compact development and intensive land use is a necessary and significant component of the urban development process. Land development and utilization guided by the compact development concept is more conducive to the city's sustainable and healthy development [38]. The process of urban development to compactness does not stop the development and utilization of land [39]. High-density development and mixed use of land is an important foundation for the construction of compact cities [11,12]. The researchers found that the level of coordination in the relationship between urban compactness and land-use efficiency is not ideal, after they systematically analyzed it from the perspective of coupled and coordinated development [40,41]. Due to the reduction in labor and capital inputs per unit of land and the expansion of land, shrinking cities have a more urgent need for efficient land use and require more compact development patterns compared with growing cities. The coordinated and interactive development of spatial compactness and intensive land use is an effective path for the sustainable development of shrinking cities. Through thorough evaluation of the existing research, it was concluded that the studies on the relationship between urban compactness and land-use efficiency have mostly focused on growing cities. This lack of attention makes it difficult to establish a systematic understanding of land use and compact development regarding shrinking cities. In order to alleviate land conflicts and achieve intensive and compact development, the coordinated development of compactness and land-use efficiency is beneficial for shrinking cities, especially in the context of China's rapid urbanization.

2.2. Analytical Framework

Maximizing the effectiveness of existing land resources is an important issue that shrinking cities face. From the theoretical perspective, shrinking cities have issues such as population loss, economic stagnation, and sometimes even land expansion [14]. Population loss directly causes lower labor factor input, while economic stagnation restricts capital factor input. Moreover, the expansion of land size dilutes the intensity of land input which is already on a declining trend. Changes in the factors of labor, capital, and land use in shrinking cities may easily lead to problems such as inefficient land use. Compact city development, with its emphasis on intensification, compactness and efficiency, is a successful strategy for resolving land-use issues in shrinking cities. Its fundamental purpose is to promote intense and efficient use of land. Furthermore, it advocates for city-scale control and the compact development of population, economy, land, and other elements within a constrained space, thereby increasing the intensity of unit land development and utilization, reducing land resource consumption. Compact city development also promotes the transformation of land expansion from extensional to connotative enhancement, which provides an external push to improve land-use efficiency. Via intensive land resource allocation, intensive and efficient land utilization creates an internal pulling force for compact urban construction. Land-use efficiency improvement entails the increase in land efficiency per unit area. The advantages of cities in terms of economic, social, and ecological development can further attract urban elements to form spatial agglomeration, fully exploit land potential, and lay a solid material foundation for compact city construction. Compact urban development can externally support the increase in land-use efficiency, and the intensive and efficient use of land can operate as an internal motivator for the construction of compact cities. Between urban compactness and land-use efficiency, there is a non-linear relationship that is both mutually restricting and stimulating, and the two combined form an organic, unified, coordinated, and orderly open system (Figure 1). Thus, coordinated development of spatial compactness and intensive and efficient land use is critical for shrinking cities in order to address urban land challenges and achieve healthy and sustainable development.

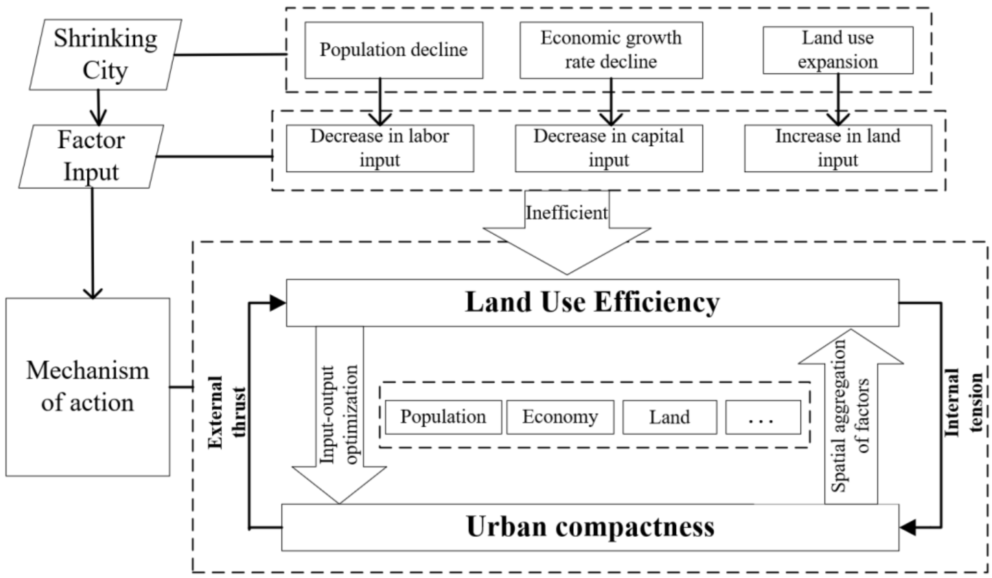

Figure 1. The coordination model of compactness and land-use efficiency in shrinking cities. (Source: Authors).

3. Data and Methods

3.1. Study Area

Northeast China is comprised of the provinces Heilongjiang, Jilin, and Liaoning, as well as 36 prefecture-level cities, autonomous prefectures, and regions. As of 2018, the Northeast region's overall population was 103.8 million, down more than four million from the 107.9 million people which were reported to live there in 2008. In comparison, the construction land area expanded by 1331 km^2 between 2008 and 2018, growing from 4730 to 6061 km^2. Numerous cities in the Northeast experienced urban shrinkage, accompanied by the development paradox of population decline and land expansion.

Urban shrinkage is a long-term and continual population decline process. In this paper, the municipal districts of prefecture-level cities were used as the study area. The prefecture-level cities consist of municipal districts and outlying county-level cities. The municipal district is usually the core area for the economic and social development of the whole city. Based on the definition of shrinking cities by Hoekveld [42], and also considering the continuity and accessibility of the data, shrinking cities are identified by the following conditions in our work: a negative cumulative population growth rate in the municipal districts during the 2008–2018 period, and five consecutive years of negative population growth (Table 1). Finally, 15 shrinking cities were selected, more specifically, Fushun, Benxi, Fuxin, and Tieling in the Liaoning Province; Liaoyuan, Tonghua, Baishan, and Baicheng in the Jilin Province; and Qiqihar, Jixi, Hegang, Yichun, Jiamusi, Qitaihe, and Suihua in the Heilongjiang Province (Figure 2).

Table 1. Changes in population and construction land in shrinking cities.

City	Population (10^4 Persons)			Construction Land (km^2)		
	2008	**2018**	**Changes**	**2008**	**2018**	**Changes**
Fushun	139.6	136	−3.6	124	141	17
Benxi	95.7	89	−6.7	70	92	22
Fuxin	77.9	74	−3.9	69	77	8
Tieling	44.6	43	−1.6	44	75	31
Liaoyuan	47.73	45	−2.73	42	46	4
Tonghua	45.27	43	−2.27	41	57	16
Baishan	59.32	53	−6.32	32	43	11
Baicheng	50.86	49	−1.86	34	45	11
Qiqihar	142.5	132	−10.5	139	141	2
Jixi	88.5	78	−10.5	97	79	−18
Hegang	68	61	−7	70	53	−17
Yichun	81	73	−8	156	152	−4
Jiamusi	82.4	76	−6.4	62	90	28
Qitaihe	53.5	47	−6.5	62	68	6
Suihua	89.7	84	−5.7	27	37	10

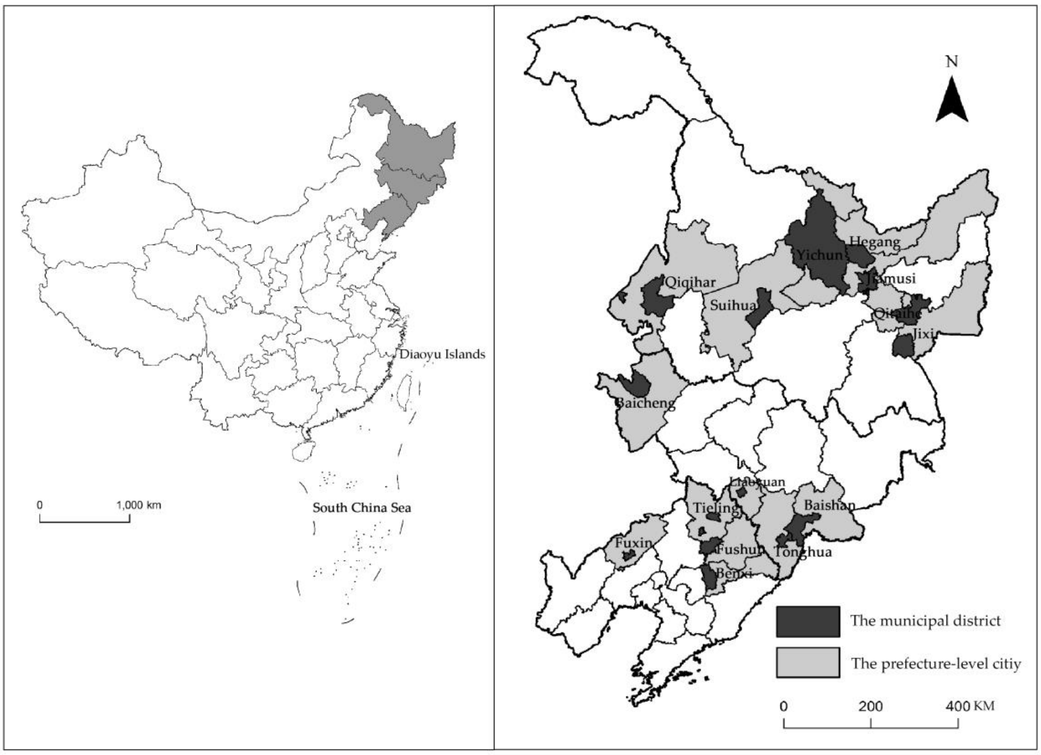

Figure 2. The distribution of shrinking cities in Northeast China. (Source: Authors).

3.2. Index System and Data Sources

3.2.1. Compactness Index System

Compact cities are defined by their intensive and efficient development, which entails the intensive use of urban elements such as population, economy, land, and infrastructure to ensure the efficient operation of urban systems. The compact city is a multidimensional and complex system influenced by numerous factors. When combined with the existing compactness evaluation index system [8,16], the indexes with high frequency of use are chosen, while those with repetitive or insufficient characterization are excluded. To construct the compactness evaluation index system (Table 2), a total of 16 indicators were selected among the four following aspects: population compactness, economic compactness, land compactness, and public service compactness. Furthermore, the index weights were determined using the entropy value method. The population compactness aspect strives for a higher population density that is suitable for living in order to ensure the vitality of urban development. The economic compactness aspect emphasizes the agglomeration of capital, labor, and other elements to increase the economic output per unit area, while the land compactness aspect prevents the city from expanding in an unplanned manner and enhances the level of intensive mixed use of land. Finally, the aspect of public services compactness emphasizes the use of public transportation, as well as the accessibility and utilization of infrastructure.

Table 2. Urban compactness evaluation index system.

Target Layer	Guideline Layer	Index Layer	Index Meaning	Weight
Compactness	Population compactness	Residential population density	Urban population/Residential land area	0.0606
		Employment population density	Number of employees in the city/Area of the city	0.0893
		Urban population density	Urban population/Urban area	0.0724
		Population growth elasticity	Urban population growth rate/Urban construction land growth rate	0.0574
	Economic compactness	GDP density	Urban GDP/Urban area	0.0984
		Fixed investment intensity	Urban fixed asset investment/ Urban area	0.1262
		Business vitality	Total retail sales of consumer goods/Urban population	0.0484
		Economic growth elasticity	Urban GDP growth rate/Urban construction land growth rate	0.0769
	Land compactness	Urban development and utilization intensity	Built-up area/Urban area	0.0960
		Land utilization	Construction land area/Built-up area	0.0355
		Mixed land index	Commercial land + industrial land/Commercial land + industrial land + residential land	0.0382
		Land use structure entropy	Entropy of residential, commercial, and industrial land	0.0312
	Public service compactness	Road area per capita index	Urban road area/Urban population	0.0361
		Public transport efficiency	Total number of urban bus passengers/Actual number of buses	0.0480
		Educational services	Number of teachers enrolled/Number of students enrolled	0.0534
		Centralized sewage treatment rate	Wastewater treatment volume/Wastewater discharge volume	0.0320

Note: Land use structure entropy = −(the proportion of residential land ln (the proportion of residential land) + the proportion of commercial land ln (the proportion of commercial land) the proportion of industrial land ln (the proportion of industrial land)).

3.2.2. Land-Use Efficiency Index System

Land use efficiency refers to an increase in the output of a unit land area related to regional social and economic activities [43]. With reference to the existing studies on the index system of land-use efficiency, we constructed the index system of land-use efficiency in terms of both inputs and outputs [22,25,33,44]. Land, capital, and labor are the most basic input factors of urban land activities. The built-up area is the area where human activities are concentrated and is the material carrier of urban production and construction activities. Total investment in fixed assets refers to the capital invested in the construction and acquisition of fixed assets, which is the main form of capital input in urban land. The secondary and tertiary industries are the main types of industries in cities, and therefore, the main labor force in cities is the employees of the secondary and tertiary industries. The benefits of land output are mainly reflected in three aspects: economic benefits, social benefits, and ecological benefits. Among the economic benefits, the economic output of urban land comes mainly from the secondary and tertiary industries due to the small share of the primary industries in cities. The living standard of urban residents is a reflection of social benefits, and the average salary of urban employees can represent the living standard of residents in a certain extent. The ecological benefits are mainly reflected in the construction of the urban ecological environment. Based on the above analysis and considering the authenticity and availability of the data, the following input indexes were chosen: the area of built-up area, the number of employees in secondary and tertiary industries, and the total investment in fixed assets. The following output indexes were chosen: the value added of secondary and tertiary industries, the average wage of urban employees, and the greening coverage rate (Table 3).

Table 3. Land-use efficiency evaluation index system.

Category	Element	Index
Inputs	Land	Built-up area
	Labor force	Number of employees in secondary and tertiary industries
	Capital	Total investment in fixed assets
Outputs	Economic benefits	Value added of secondary and tertiary industries
	Social benefits	Average salary of urban employees
	Ecological benefits	Green coverage rate

3.2.3. Selection of Influencing Factors of Coupling Coordination Degree

The coupled coordination of urban compactness and land-use efficiency is a complex process. Therefore, in light of the current state of urban compact development and land use, and according to previous research, the coupled coordination degree of shrinking urban compactness and land-use efficiency were selected as the explained variables in Northeast China from 2008 to 2018. GDP per capita, average employment in secondary and tertiary industries, actual foreign investment utilized, the ratio of science and technology expenditure to GDP, the ratio of secondary and tertiary industries to GDP, and the ratio of fiscal expenditure to GDP were selected as explanatory variables from six aspects. These aspects include the economic development, population size, openness to the outside world, technological development, industrial structure, and government regulation. The purpose was to systematically investigate the main driving factors behind the coupled and coordinated development of the shrinking cities.

3.2.4. Data Sources

The data involved in this paper were obtained from multiple sources, including the 2008–2019 China Urban Statistical Yearbook, China Urban Construction Statistical Yearbook, China Population and Employment Statistical Yearbook, Liaoning Provincial Statistical Yearbook, Jilin Provincial Statistical Yearbook, and Heilongjiang Provincial Statistical Yearbook. Moreover, the cities' national economic and social development statistical bulletins supplemented the data. A small amount of missing data was obtained by interpolation estimation.

3.3. Research Methods

3.3.1. Compactness Measurement Method

The entropy method for objectively assigning the weight values to various indexes based on their relative change degree in relation to the overall system, which can be used to create a comprehensive measurement of multiple indexes, was chosen [8]. Because the entropy value method is widely used to determine the index weight values, the detailed steps for its implementation are omitted. The data were standardized using the extreme value standardization method, and the evaluation value of urban compactness was calculated using the weighted summation method. The formula for compactness evaluation value is the following:

$$C_i = \sum (w_j \cdot x_{ij}) \tag{1}$$

In which x_{ij} is the standardized value of the jth indicator of the city i; w_j represents the weight of the jth indicator; and C_{ij} signifies the compactness evaluation value of the city i.

3.3.2. Land-Use Efficiency Measurement Method

Although data envelopment analysis (DEA) is a nonparametric method for evaluating multi-input and multi-output efficiency, it suffers from variable relaxation. Tone (2001) proposed the Slack-Based Measure (SBM) model to address the issue, but the model is still uncapable of evaluating multiple efficient decision units [45]. Thus, Tone (2002) proposed the Super Efficiency-Slack Based Measure model to solve the problem [46]. The Super-SBM model was used in this research to quantify the land-use efficiency of the shrinking cities in Northeast China from an input perspective. The calculation was based on the theory of the constant returns to scale. The adjusted model is as follows:

$$\min\rho = \frac{1 + \frac{1}{m}\sum\limits_{i=1}^{m} s_i^- / x_{ik}}{1 - \frac{1}{s}\sum\limits_{r=1}^{s} s_r^+ / y_{rk}} \tag{2}$$

$$s.t.\begin{cases} x_{ik} \geq \sum\limits_{j=1,\, j\neq k}^{n} x_{ij}\lambda_j - s_i^- (i = 1, 2, \ldots . m) \\ y_{rk} \leq \sum\limits_{j=1,\, j\neq k}^{n} y_{rj}\lambda_j + s_r^+ (r = 1, 2, \ldots . s) \\ \lambda \geq 0, s^- \geq 0, s^+ \geq 0, j \neq k \end{cases} \tag{3}$$

In which ρ is the measured efficiency value; m represents the number of input indicators; s signifies the number of output indicators; λ reflects the weight of the efficiency assessment process; s_r^- denotes the input slack variables; s_r^+ denotes the output slack variables; and x_{ik} and $y_{rk,}$ respectively, denote the input and output values of the evaluation unit during a certain period.

3.3.3. Coordination Measurement Methods for Compactness and Land-Use Efficiency

Coupling refers to the phenomenon of two systems or modes of motion affecting each other and possibly even combining through various interactions. The coupling degree primarily indicates the strength of the interaction between or within the system but does not indicate the quality of the development consistency. Therefore, the coupled coordination degree model is introduced to measure the degree of coordination and advancement between or within system elements. By combining the findings of Gong et al. (2021) and Xie et al. (2021), this paper developed a model of coupled coordination degree of urban compactness and land-use efficiency [35,36]. The model is shown in the Equations (4)–(6) below.

$$C = 2\left[(P \cdot Q)/(P + Q)^2\right]^{\frac{1}{2}} \tag{4}$$

$$D = (C \cdot T)^{1/2} \tag{5}$$

$$T = \alpha P + \beta Q \tag{6}$$

In which C is the coupling degree of compactness and land-use efficiency; P denotes the compactness, Q reflects the land-use efficiency; D represents the coupled coordination degree of the two values; T is the comprehensive coordination index; and α and β are determining coefficients indicating the relative importance of compactness and land-use efficiency, where $\alpha + \beta = 1$. In this paper, urban compactness and land-use efficiency were considered equally important, so both α and β had the value of 0.5.

To better characterize the state of coordination between urban compactness and land-use efficiency, the level and status of coupled coordinated development were divided according to previous research and the region's actual situation [47]. This was all combined with the quadrant diagram classification identification method, as can be seen in Table 4. Furthermore, the compactness (P) and land-use efficiency (Q) scores were standardized to obtain ZP and ZQ with the following equations.

$$ZP = \left(P_{\lambda i} - \overline{P}\right)/S_P, \quad ZQ = \left(Q_{\lambda i} - \overline{Q}\right)/S_Q \tag{7}$$

In which $P_{\lambda i}$ and $Q_{\lambda i}$ denote the compactness and land-use efficiency of the ith city in a year λ; $\overline{P}$ and $\overline{Q}$ represent the mean of the two; S_P and $S_{Q,}$ respectively, symbolize the standard deviation of the two; and ZP and ZQ represent the relationship between compactness and land-use efficiency.

Table 4. The coordinated development state of the compactness and land-use efficiency and relationship delineation.

Coupled Coordination Degree	Coordination Level	Coordination of Relationships	The Degree of Deviation
$0 \leq D < 0.1$ $0.1 \leq D < 0.2$ $0.2 \leq D < 0.3$ $0.3 \leq D < 0.4$ $0.4 \leq D < 0.5$	Extreme imbalance Serious imbalance Moderate imbalance Mild imbalance On the verge of imbalance	ZP > ZQ Lagging land-use efficiency	$0 \leq N \leq 0.5$ Low deviation $0.5 < N \leq 1$ Moderate deviation $N > 1$ High deviation
$0.5 \leq D < 0.6$ $0.6 \leq D < 0.7$ $0.7 \leq D < 0.8$ $0.8 \leq D < 0.9$ $0.9 \leq D < 1$	Barely coordination Primary coordination Intermediate coordination Good coordination High-quality coordination	ZP < ZQ Lagging compactness	$0 \leq N \leq 0.5$ Low deviation $0.5 < N \leq 1$ Moderate deviation $N > 1$ High deviation

The deviation between the two is signified by $N = |ZP - ZQ|$. The quadrant diagram representing the relationship between urban compactness and land-use efficiency was constructed with ZP as the horizontal coordinate and ZQ as the vertical coordinate (Figure 3).

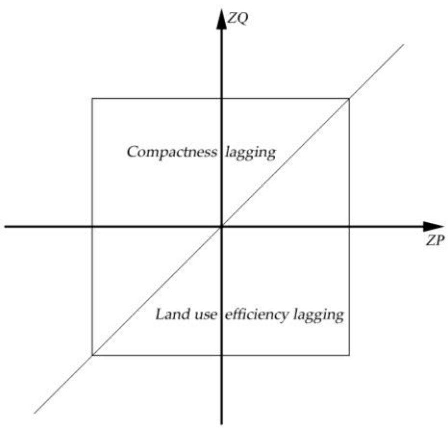

Figure 3. The quadrant diagram of the relationship between the compactness and land-use efficiency. (Source: Authors).

3.3.4. Measurement Model of Coordination Influence Factors

The value of coupled coordination measured in this paper was between 0 and 1, which served as a "restricted dependent variable". Moreover, the use of the Ordinary Least

Squares (OLS) regression would ultimately lead to biased estimated results. Therefore, the Tobit model was used to investigate the factors that influence the coupled coordination of the shrinking urban compactness and land-use efficiency.

$$Y_{it} = \begin{cases} Y_{it}^{*} = \beta_0 + \sum_{t=1}^{n} \beta_t x_{it} + \varepsilon_{it}, Y_{it}^{*} > 0 \\ 0, \quad Y_{it}^{*} \leq 0 \end{cases} \quad (8)$$

In which y_{it} is the response variable; x_{it} represents the explanatory variable; β_0 signifies the constant term; β_t represents the estimated coefficient of the model; t = 1, 2, 3, . . . , n, n is the number of explanatory variables; and ε_{it} is the unique random error disturbance term, and it was ε_{it}~(0, σ^2).

4. Results

4.1. Evolutionary Characteristics of Compactness and Land-Use Efficiency in Shrinking Cities

4.1.1. Evolutionary Characteristics of Compactness in Shrinking Cities

The mean compactness of 15 shrinking cities in the Northeast China increased from 0.317 in 2008 to 0.350 in 2018, and the compactness of 13 researched cities, except that of Fushun and Suihua, improved. This indicates that the compactness of most shrinking cities has improved, however, the overall level was not high. The standard deviation of the compactness decreased from 0.158 to 0.154, demonstrating that the compactness disparity between the cities continued to be substantial (Figure 4). Due to population loss and the decline in economic growth, it was difficult to evenly distribute the limited resources of shrinking cities on a larger scale of land. To combat this, adjustments were made in urban planning, that is, the limited resources were concentrated on land with good infrastructural conditions, thus enhancing urban compactness. Enhancing urban compactness in this context may help moderate "pie-spreading" urban expansion, accelerate the transition of urban development from outward expansion to internal improvement, and boost the operational efficiency of shrinking cities.

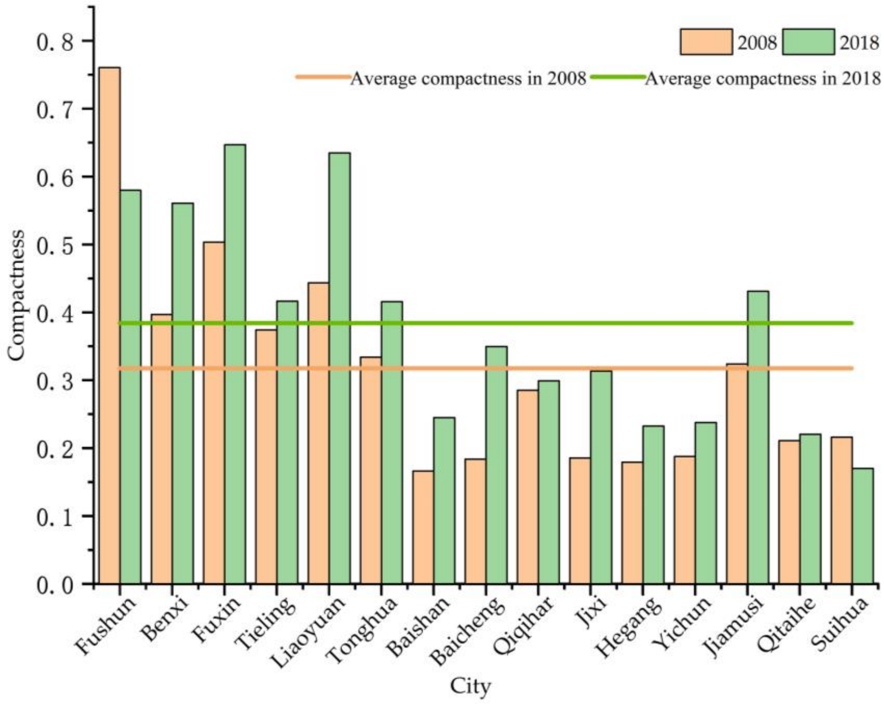

Figure 4. The compactness of shrinking cities from 2008 to 2018. The yellow line is the average compactness of the 15 shrinking cities in 2008; the green line is the average compactness of the 15 shrinking cities in 2018. (Source: Authors).

4.1.2. The Evolutionary Characteristics of Land-Use Efficiency in Shrinking Cities

The mean value of land-use efficiency fluctuated between 0.938 in 2008 and 0.993 in 2018. Furthermore, the number of cities with land-use efficiency greater than the mean and reaching DEA validity increased from seven to eight, indicating that the overall land-use efficiency of shrinking cities tended to improve, although it has not reached DEA validity. The standard deviation for land-use efficiency decreased from 0.453 to 0.329, indicating that while the disparity in land-use efficiency between shrinking cities was narrowing, it remained substantial (Figure 5). Among the cities with relatively effective land-use efficiency, small shrinking cities such as Tieling and Liaoyuan had effectively avoided element redundancy through appropriate and smaller scale input factors and achieved efficient land-use development. On the other hand, larger shrinking cities such as Hegang and Jiamusi focused on the full utilization of input elements for land development and utilization and efficiently transformed them into output elements. However, half of the shrinking cities had not yet achieved DEA effectiveness, indicating that input elements were not being utilized efficiently and were not being fully transformed into effective outputs, which implied that much room for improvement remains.

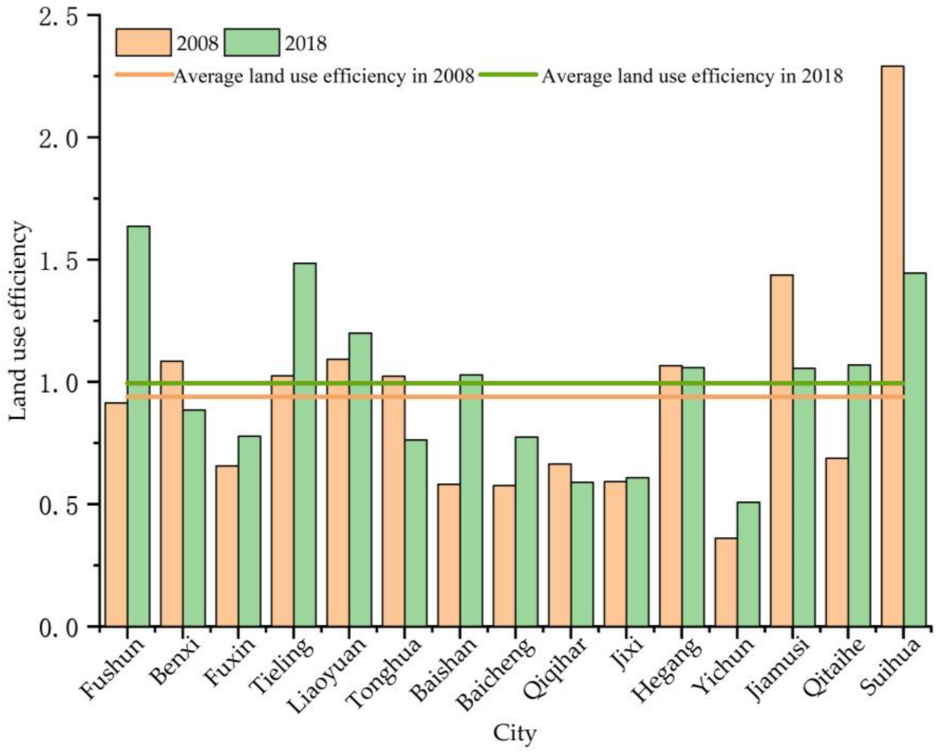

Figure 5. The land-use efficiency of shrinking cities from 2008 to 2018. The yellow line is the average land-use efficiency of the 15 shrinking cities in 2008; the green line is the average land-use efficiency of the 15 shrinking cities in 2018. (Source: Authors).

4.2. Coordination of Compactness and Land-Use Efficiency in Shrinking Cities

4.2.1. The Overall Change in the Coupled Coordination between the Compactness and Land-Use Efficiency

Between 2008 and 2018, the coupled coordination of compactness and land-use efficiency in 15 shrinking cities in Northeast China grew steadily. The coordination degree increased from 0.713 to 0.767, but it remained in the overall state of intermediate coordination (Table 5). The increase in the coordination degree can be noticed in 11 cities, indicating that the coordination level between compactness and land-use efficiency in the majority of shrinking cities developed to a satisfactory level. Baishan and Baicheng had seen the most improvement in coordination with 27% and 26.40%, respectively, both moving from barely coordinated to intermediately coordination status. Furthermore, the cities of Tonghua, Qiqihar, Jiamusi, and Suihua all showed a decrease, with Suihua experiencing the greatest decrease, by 16.03%. The city of Suihua went from a high level of coordination to the intermediate coordination status. With a mean value of 0.914, Liaoyuan had the most significant coordination, indicating it was in the state of high-quality coordination. On the other hand, Yichun had the lowest coordination mean value of 0.579, meaning that it was barely coordinated. The gap between the two cities was 0.335, which means that there were significant differences in the coordination status among the shrinking cities, which were closely related to the variations in the scale and the level of economic and social development of the shrinking cities.

Table 5. The coupling coordination degree of shrinking city compactness and land-use efficiency from 2008 to 2018.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
Fushun	0.913	0.871	0.891	0.866	0.843	0.806	0.868	0.869	0.914	0.924	0.987	0.887
Benxi	0.810	0.813	0.832	0.862	0.841	0.790	0.857	0.868	0.819	0.843	0.840	0.834
Fuxin	0.759	0.730	0.784	0.815	0.799	0.774	0.838	0.967	0.888	0.868	0.843	0.824
Tieling	0.787	0.859	0.796	0.873	0.862	0.859	0.794	0.817	0.841	0.911	0.887	0.844
Liaoyuan	0.835	0.887	0.866	0.951	0.925	0.930	0.948	0.916	0.931	0.932	0.934	0.914
Tonghua	0.765	0.781	0.787	0.793	0.827	0.788	0.811	0.873	0.767	0.780	0.751	0.793
Baishan	0.558	0.707	0.688	0.773	0.756	0.679	0.766	0.739	0.688	0.763	0.709	0.711
Baicheng	0.571	0.610	0.657	0.664	0.670	0.646	0.635	0.703	0.707	0.800	0.722	0.671
Qiqihar	0.660	0.615	0.576	0.684	0.678	0.690	0.689	0.708	0.687	0.702	0.648	0.667
Jixi	0.576	0.614	0.636	0.671	0.658	0.637	0.654	0.659	0.598	0.627	0.661	0.636
Hegang	0.662	0.689	0.711	0.687	0.671	0.614	0.721	0.722	0.780	0.725	0.705	0.699
Yichun	0.511	0.524	0.530	0.550	0.577	0.601	0.590	0.659	0.601	0.631	0.590	0.579
Jiamusi	0.826	0.817	0.825	0.863	0.856	0.849	0.821	0.852	0.824	0.841	0.822	0.836
Qitaihe	0.618	0.617	0.622	0.695	0.682	0.643	0.602	0.718	0.644	0.699	0.697	0.658
Suihua	0.839	0.866	0.854	0.960	0.918	0.809	0.830	0.831	0.759	0.793	0.705	0.833
Mean	0.713	0.733	0.737	0.780	0.771	0.741	0.762	0.793	0.763	0.789	0.767	
Std.	0.122	0.114	0.110	0.114	0.104	0.099	0.104	0.094	0.104	0.096	0.110	

4.2.2. The Spatial and Temporal Divergence Pattern of the Coordination Degree between Compactness and Land-Use Efficiency

In general, significant spatial and temporal variations exist in the coupled coordination of compactness and land-use efficiency in Northeast China's shrinking cities (Figure 6). In 2008, all the shrinking cities in the region achieved the barely coordinated and above status, but the level of coordination was low and the disparity between the cities was significant. Only the cities of Benxi, Liaoyuan, Jiamusi, Suihua, and Fushun reached the good coordination status and above. On the other hand, in 2018, the overall coordination level significantly improved compared with the initial year. Among the 11 cities with improved coupled coordination, seven cities, including Fuxin, Tieling, Liaoyuan, Baishan, Baicheng, Jixi, and Hegang, also improved their coordination status, and only Suihua's coordination status decreased. The spatial variation in the coupled coordination degree was evident. The overall distribution pattern could be described as high in the south and low in the north, and the disparity between the north and the south tended to further increase. The low-value cities were primarily concentrated in the peripheral areas of Northeast China, while the high-value cities were distributed near the border of Jilin and Liaoning provinces.

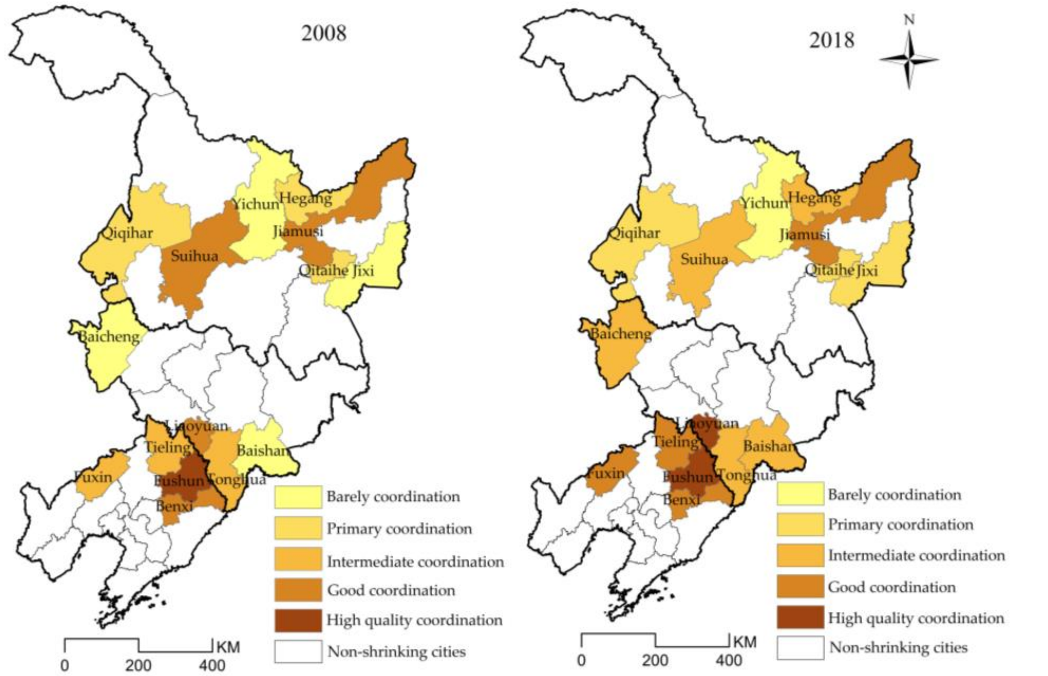

Figure 6. The spatial pattern of the coupling coordination degree of shrinking cities in 2008 and 2018. (Source: Authors).

4.2.3. The Changes in the Coordinated Relationship between the Compactness and Land-Use Efficiency

In the coordinated relationship between urban compactness and land-use efficiency, the land-use efficiency of seven cities, including Fushun and Benxi, deviated from compactness in 2008. To be precise, the land-use efficiency lagged behind compactness, and two of them are highly lagged. In addition, eight cities, among which were Baishan and Hegang, lagged behind the development of compactness, and three of them were highly lagged (Figure 7). In the early studied period, cities excessively focused on economic growth, and the land-oriented development model resulted in rapid city scale expansion, but at the expense of efficient land use. By 2018, the problem of lagging land-use efficiency had deepened, with the number of cities with lagging land-use efficiency increasing to nine and the proportion of medium- or high-lagging cities also increasing. Urban sprawl had been contained to some extent through increased local government control of land grants. However, urban land problems caused by expansion were difficult to reverse in a short period of time and the ever-present pressure of urban shrinking resulted in the aggravation of lagging land-use efficiency. From 2008 to 2018, only Suihua experienced a simultaneous decline in compactness and land-use efficiency, while eight cities such as Fuxin and Tieling achieved synergistic improvement. Moreover, six cities such as Fushun and Benxi experienced differential changes, primarily manifesting as an improved state of compactness and land-use efficiency decline. This may indicate that shrinking cities faced greater issues in land-use efficiency improvement than compact development.

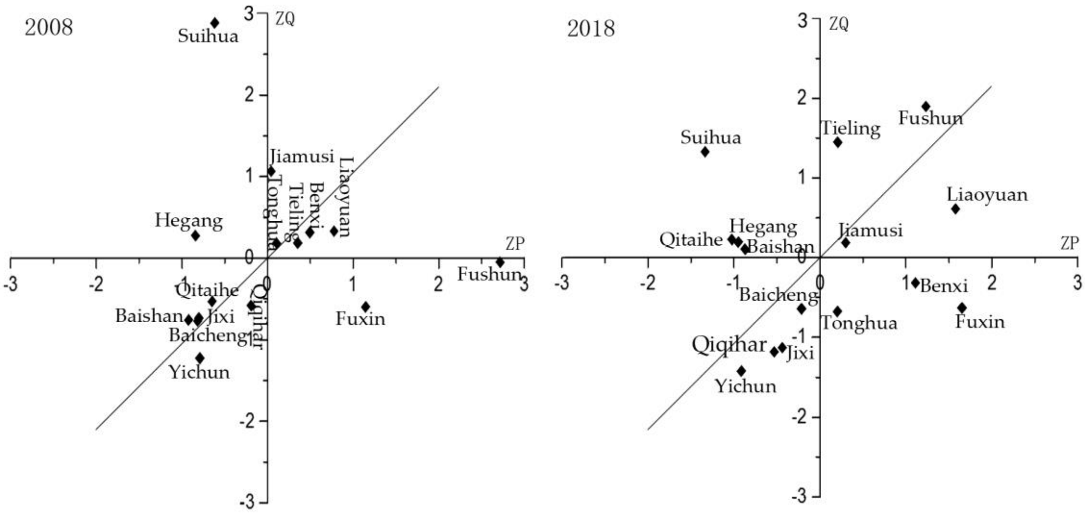

Figure 7. The quadrant diagram of coordinated relationship between compactness and land-use efficiency in 2008 and 2018. (Source: Authors).

4.3. The Mechanisms Influencing the Coordination Degree of Compactness and Land-Use Efficiency in Shrinking Cities

According to the findings (Table 6), both economic development and population size have positive effects on coordination. Shrinking cities with a high level of economic development benefit from the significant spatial agglomeration of capital, labor, technology, and other elements, as well as comprehensive urban infrastructure construction, which facilitates land development at a high density. Simultaneously, the cost of land development and utilization was also high in economically developed cities. In order to maximize economic benefits, the intensive and efficient land use in the developed cities is stimulated, which provides excellent support for coordination of compact urban development and intensive and efficient land use. However, shrinking cities are currently confronted with declining economic growth and slow development, which makes it difficult to further improve the coordination of cities with medium and high levels of coordination, such as Fushun and Benxi. The population of Northeast China's shrinking cities is constantly declining, which limits the overall coordination level of compact development and efficient land use to some extent.

Table 6. Regression results according to Tobit model.

Variables	Coefficient	t-Value
Economic development	0.052 *** (0.008)	6.85
Population size	0.058 *** (0.007)	8.20
External openness	−0.006 (0.007)	−0.86
Technological development	−0.013 ** (0.006)	−2.22
Industrial Structure	−0.036 *** (0.007)	−4.95
Government regulation	−0.013 ** (0.006)	−2.08

Note: ** and *** indicate significance at 0.05 and 0.01 confidence levels, respectively; standard errors of each variable are in parentheses.

External openness is negatively related to coordination but does not reach statistical significance, indicating that foreign capital does not successfully contribute to the compact development and land-use efficiency of shrinking cities. However, the three factors of technological development, industrial structure, and government regulation have historically played a positive role in the influence mechanism of urban compactness or land-use efficiency [26,36,48]. However, mainly due to special characteristics of the shrinking cities studied, these factors exhibited a negative effect, which was in line with other studies [34,37]. Because shrinking cities such as Qiqihar, Yichun, and Jixi were mostly located away from the Harbin–Dalian city axis and were not sufficiently driven by the core cities, they relied more on self-development [49]. In comparison with growing cities, their industrial structure contained a higher proportion of resource-based industries, which had long been the pillars of the cities and were critical to urban development [50]. However, the high demand and consumption of land by resource-based industries made it difficult for shrinking cities to realize compact development and intensive land use. Long-term reliance on resource-based industries had shifted the focus of shrinking city policies significantly, mostly toward the resource-based industries. Moreover, a large proportion of government spending, including science and technology, was directed towards resource-based industry development. This made it difficult for science and technology development to effectively promote the coordinated development of compactness and land-use efficiency in the short term. The increase in land scale, combined with inefficient planning and management, had resulted in the unsystematic development of a great amount of land, impeding the construction of compact cities and efficient land use. Moreover, these factors were significant contributors to the lagging land-use efficiency.

5. Discussion

Cities that are shrinking face a variety of challenges, including population loss, economic stagnation, and land expansion. Compact land development is more conducive to the sustainable and healthy development of such cities [38], while the intensive and efficient use of land is also a critical component of compact city construction [11]. Compact development, intensive land use and their relationship have gradually gained attention in a variety of fields. However, the majority of existing research focuses on growing cities, and the relationship between compact development and intensive land use is not fully explored during the urban shrinkage phase. This study constructs an analytical framework for the study of the coordinated interaction between urban compactness and land-use efficiency. The analytical framework is developed in the context of urban shrinkage and analyzes in detail the interaction mechanism between compactness and land-use efficiency in shrinking cities. An empirical study of 15 shrinking cities in Northeast China shows that the proposed analytical framework is capable of effectively guiding the investigation of the relationship between compactness and land-use efficiency in shrinking cities and is broadly applicable. The degree and state of coordination between compactness and the land-use efficiency of shrinking cities in Northeast China were found to be greater than in growing cities. This could be due to the method which was used to measure land-use efficiency in this paper. In comparison with the traditional DEA model, the Super-SBM model used in this paper was able to compare multiple effective decision units which had efficiency values greater than one. This may more accurately reflect the current state of land-use efficiency in shrinking cities. Throughout the study period, the coordinated development of compactness and land-use efficiency improved in the majority of shrinking cities, and the coordination status also improved or remained stable. This result was consistent with the findings of a related study by Tang and Chen (2019) for Anhui Province [40]. Unlike the overall improvement in coordination levels of growing cities [42], the overall improvement in coordination levels of shrinking cities was insignificant, with the mean value of coordination increasing by only 0.054. The reason for the improvement of coordination in the majority of shrinking cities but not in the entire region could be related to the fact that the compactness of shrinking cities, land-use efficiency, and the coordination of both in Northeast China's cities were highly disparate. This then resulted in coordination improvement in the majority of cities but ineffectively contributed to overall improvement. In addition, this paper not only used the coupled coordination degree model to analyze the coordination degree and coordination status of compactness and land-use efficiency, but also used the quadrant diagram method to study the coordinated relationship and deviation degree of compactness and land-use efficiency. As the coordinated relationship between compactness and land-use efficiency evolved over time, growing cities primarily exhibited a gradual aggravation of compactness lag [51], whereas shrinking cities mainly showed an aggravation of the land-use efficiency lag. The reason for this could be that as land-use constraints were gradually tightened, local governments cautiously increased the area of land offered for sale. Moreover, the rate of land expansion slowed or stagnated in the majority of shrinking cities, alleviating the issue of irrational land use that constrains compact urban development. However, the urban land problems caused by the previous sprawl are difficult to reverse in a short time period. Compared with growing cities with population growth and rapid economic development, shrinking cities, with population loss and declining economic growth, are difficult to maintain efficient investments in land; thus, inefficient land use is inevitable. Additionally, as cities transform and develop, the transformation of resource-based industries results in the abandonment of significant amounts of industrial land, exacerbating the problem of lagged land-use efficiency in shrinking cities.

While the fundamental transformation of the urban shrinkage dilemma is difficult, cities can still employ diverse strategies in their future development and planning to promote coordinated and interactive development of urban compactness and land-use efficiency [52]. When it comes to industrial transformation and development, the proportion of traditional resource-based industries with high land consumption and low output should be gradually reduced, while the new industries and business models should be promoted. Furthermore, there should be urban economic transformation and development promotion, increased resource concentration and land efficiency in conjunction with economic development. It is also proposed that active population and talent policies be promoted, population loss controlled, and high-quality talents reintroduced to the cities. This would provide sufficient labor resources for urban development and gradually restore the vitality of local urban development. Moreover, support and capital investment should be increased, especially in the field of high-tech industries, so that depth and breadth of urban land use would be improved, and the enhancement of urban land marketization should be enhanced. Additionally, land resource supervision should be tightened, as well as planning, while the inefficient stock of land should be revitalized and so on.

6. Conclusions

The purpose of this study is to investigate the coordinated relationship between urban compactness and land-use efficiency in shrinking cities, a type of city that is undergoing a unique developmental stage. An analytical framework for the coordinated interaction between compactness and land-use efficiency in the context of urban shrinkage is first developed, and an empirical study of 15 shrinking cities in Northeast China is conducted under this framework. The entropy method is applied to measure urban compactness in four aspects: population, economy, land, and public services, while the Super-SBM model is used to quantitatively evaluate land-use efficiency from the perspective of inputs and outputs. In addition, the level and state of coordinated development are studied by coupled coordination degree model, and the quadrant diagram method is employed to further explore the coordinated relationship and deviation degree. The influence mechanism of coordinated development was also analyzed. The following major conclusions could be drawn. (1) The compactness of Northeast China's shrinking cities was low, and land-use efficiency had marginally improved, with nearly half of the cities still failing to achieve relatively efficient land use. It is also important to note that the differences in compactness and land-use efficiency between the shrinking cities were fairly significant. (2) Throughout the study period, the compactness and land-use efficiency of eight shrinking cities had synergistically improved, while the coordination degree of 11 cities had also improved. However, the improvement of each city and the overall regional coordination degree were not significant, while the coordination status always remained intermediate. In terms of the coordinated relationship, the issue of lagged land-use efficiency in shrinking cities was notable and tended to exacerbate. The efficient use of land should be further strengthened during the compact development process of shrinking cities. The spatial difference in the degree of coordination was significant and tended to grow, while the issue of coordinated development was more severe at the shrinking cities located in the region's periphery. (3) While increased economic development and population growth could facilitate the coordinated development of urban compactness and land-use efficiency, scientific and technological advancements, industrial structure, and government regulation did not. It is possible that the problems of constant population loss, slow economic development, and land expansion in shrinking cities limit the improvement of the coordination of compactness and land-use efficiency. In addition, to address the issue of lagging land-use efficiency development in shrinking cities, it is necessary to continue exploring the possibility of enhancing land development and utilization efficiency through land expansion control.

Moreover, it should be stated that this study has some shortcomings. Given the availability and convenience of data, the index system for compactness and land-use efficiency in shrinking cities still requires improvement and supplementation in terms of exhaustiveness and precision. Due to the lack of relevant data, the impact of undesirable output such as wastewater and waste gas was not considered when measuring land-use efficiency in shrinking cities. Meanwhile, future research should broaden the time scale of the study, examine the distinct characteristics of compactness and land-use efficiency in the two different stages of urban growth and shrinkage, and strengthen the comparative study of urban growth and shrinkage problems.

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References

1. Deng, H.; Zhang, K.; Wang, F.; Dang, A. Compact or disperse? Evolution patterns and coupling of urban land expansion and population distribution evolution of major cities in China, 1998–2018. *Habitat Int.* **2021**, *108*, 102324. [CrossRef]
2. Huang, Z.; Du, X. Urban land expansion and air pollution: Evidence from China. *J. Urban Plan. Dev.* **2018**, *144*, 5018017. [CrossRef]
3. Yang, D.; Long, Y.; Yang, W.; Sun, H. Losing population with expanding space: Paradox of urban shrinkage in China. *Mod. Urban Res.* **2015**, *9*, 20–25. [CrossRef]
4. Hu, Y.; Wang, Z.; Deng, T. Expansion in the shrinking cities: Does place-based policy help to curb urban shrinkage in China? *Cities* **2021**, *113*, 103188. [CrossRef]
5. Suen, I.-S. The impact of compact and mixed development on land value: A case study of Richmond, Virginia. *Urban Sci.* **2018**, *2*, 47. [CrossRef]
6. Burton, E. Measuring urban compactness in UK towns and cities. *Environ. Plan. B* **2002**, *29*, 219–250. [CrossRef]
7. Lan, T.; Shao, G.; Xu, Z.; Tang, L.; Sun, L. Measuring urban compactness based on functional characterization and human activity intnsity by integrating multiple geospatial data sources. *Ecol. Indic.* **2021**, *121*, 107177. [CrossRef]
8. Huang, Y.; Dong, S.; Bai, Y. Spatial-temporal features of relationship between urban compactness and urban efficiency in China. *China Popul. Resour. Environ.* **2015**, *25*, 64–73. [CrossRef]

9. Liu, Y.; Song, Y.; Song, X. An empirical study on the relationship between urban compactness and CO_2 efficiency in China. *Habitat Int.* **2014**, *41*, 92–98. [CrossRef]
10. Steurer, M.; Bary, C. Measuring urban sprawl using land use data. *Land Use Policy* **2020**, *97*, 104799. [CrossRef]
11. Zhao, F.; Tang, L.; Qiu, Q.; Wu, G. The compactness of spatial structure in Chinese cities: Measurement, clustering patterns and influencing factors. *Ecosyst. Health Sustain.* **2020**, *6*, 1743763. [CrossRef]
12. Abdullahi, S.; Pradhan, B.; Mansor, S.; Shariff, A.R.M. GIS-based modeling for the spatial measurement and evaluation of mixed land use development for a compact city. *Gisci. Remote Sens.* **2015**, *52*, 18–39. [CrossRef]
13. Fang, C.; Qi, W.; Song, J. Researches on comprehensive measurement of compactness of urban agglomerations in China. *Acta Geogr. Sin.* **2008**, *63*, 1011–1021. [CrossRef]
14. Meng, X.; Wang, D.; Li, H. Correlation between urban shrink and urban compactness ratio in old industrial city: Taking Siping city in Jilin Province as an example. *Econ. Geogr.* **2019**, *39*, 67–74. [CrossRef]
15. Hamidi, S.; Zandiatashbar, A.; Bonakdar, A. The relationship between regional compactness and regional innovation capacity (RIC): Empirical evidence from a national study. *Technol. Forecast. Soc. Chang.* **2018**, *142*, 394–402. [CrossRef]
16. Liu, R.; Ba, D. The relationship between urban compactness and urbanization level in capital cities of China. *J. Nat. Resour.* **2020**, *35*, 586–600. [CrossRef]
17. Liu, X.; Wang, M.; Qiang, W.; Wu, K.; Wang, X. Urban form, shrinking cities, and residential carbon emissions: Evidence from Chinese city-regions. *Appl. Energ.* **2020**, *261*, 114409. [CrossRef]
18. Wang, M.; Madden, M.; Liu, X. Exploring the relationship between urban forms and CO_2 emissions in 104 Chinese cities. *J. Urban Plan. Dev.* **2017**, *143*, 04017014. [CrossRef]
19. Xu, G.; Zhou, Z.; Jiao, L.; Zhao, R. Compact urban form and expansion pattern slow down the decline in urban densities: A global perspective. *Land Use Policy* **2020**, *94*, 104563. [CrossRef]
20. Dong, T.; Jiao, L.; Xu, G.; Yang, L.; Liu, J. Towards sustainability? Analyzing changing urban form patterns in the United States, Europe, and China. *Sci. Total Environ.* **2019**, *671*, 632–643. [CrossRef]
21. Ahmad, M.; Rehman, A.; Shah, S.A.A.; Solangi, Y.A.; Chandio, A.A.; Jabeen, G. Stylized heterogeneous dynamic links among healthcare expenditures, land urbanization, and CO_2 emissions across economic development levels. *Sci. Total Environ.* **2021**, *753*, 142228. [CrossRef] [PubMed]
22. Bao, Z.; Liu, C.; Zhang, J. Comprehensive appraise to the efficiency of urban land use. *Urban Probl.* **2009**, *165*, 46–50.
23. Tang, Y.; Wang, K.; Ji, X.; Xu, H.; Xiao, Y. Assessment and spatial-temporal evolution analysis of urban land use efficiency under green development orientation: Case of the Yangtze River Delta urban agglomerations. *Land* **2021**, *10*, 715. [CrossRef]
24. Dong, Y.; Jin, G.; Deng, X. Dynamic interactive effects of urban land-use efficiency, industrial transformation, and carbon emissions. *J. Clean. Prod.* **2020**, *270*, 122547. [CrossRef]
25. Ge, X.; Liu, X. Urban land use efficiency under resource-based economic transformation—A case study of Shanxi Province. *Land* **2021**, *10*, 850. [CrossRef]
26. Chen, W.; Chen, W.; Ning, S.; Liu, E.; Zhou, X.; Wang, Y.; Zhao, M. Exploring the industrial land use efficiency of China's resource-based cities. *Cities* **2019**, *93*, 215–223. [CrossRef]
27. Zhao, Q.; Bao, H.X.H.; Zhang, Z. Off-farm employment and agricultural land use efficiency in China. *Land Use Policy* **2021**, *101*, 105097. [CrossRef]
28. Huang, Z.; He, C.; Zhu, S. Do China's economic development zones improve land use efficiency? The effects of selection, factor accumulation and agglomeration. *Landsc. Urban Plan.* **2017**, *162*, 145–156. [CrossRef]
29. Yan, S.; Peng, J.; Wu, Q. Exploring the non-linear effects of city size on urban industrial land use efficiency: A spatial econometric analysis of cities in eastern China. *Land Use Policy* **2020**, *99*, 104944. [CrossRef]
30. Tang, Y.; Wang, C.; Wang, R.; Xue, M.; Dou, W. Coupling research on urban expansion and land use efficiency based on smart development: A case of Jinan's core area. *Human Geogr.* **2020**, *35*, 91–98. [CrossRef]
31. Tian, L.; Chen, J.; Gao, J. Research of coupling relationship of urban spatial structure compactness and land use efficiency: A case study of Nanjing. *Resour. Environ. Yangtze Basin* **2017**, *26*, 26–34. [CrossRef]
32. Guastella, G.; Pareglio, S. Urban spatial structure and land use fragmentation: The case of Milan FUA. *Aestimum* **2016**, *69*, 153–164. [CrossRef]
33. Gao, X.; Zhang, A.; Sun, Z. How regional economic integration influence on urban land use efficiency? A case study of Wuhan metropolitan area, China. *Land Use Policy* **2019**, *90*, 104329. [CrossRef]
34. He, H.; Peng, C. The spatial-temporal evolution and the interactive effect between urban industrial structure transformation and land use efficiency. *Geogr. Res.* **2017**, *36*, 1271–1282. [CrossRef]
35. Gong, Q.; Guo, G.; Li, S.; Liang, X. Examining the coupling coordinated relationship between urban industrial co-agglomeration and intensive land use. *Land* **2021**, *10*, 499. [CrossRef]
36. Xie, X.; Fang, B.; Xu, H.; He, S.; Li, X. Study on the coordinated relationship between urban land use efficiency and ecosystem health in China. *Land Use Policy* **2021**, *102*, 105235. [CrossRef]
37. Zhang, H.; Yang, Q. Urban land use efficiency and influencing factors of shrinking cities in China. *Human Geogr.* **2021**, *36*, 108–116. [CrossRef]
38. Abdullahi, S.; Pradhan, B. Land use change modeling and the effect of compact city paradigms: Integration of gis-based cellular automata and weights-of-evidence techniques. *Environ. Earth Sci.* **2018**, *77*, 251. [CrossRef]

39. Cortinovis, C.; Haase, D.; Zanon, B.; Geneletti, D. Is urban spatial development on the right track? Comparing strategies and trends in the European Union. *Landsc. Urban Plan.* **2019**, *181*, 22–37. [CrossRef]
40. Tang, H.; Chen, S. Coupling analysis of urban compactness and land use efficiency in Anhui Province. *J. Subtrop. Resour. Environ.* **2019**, *14*, 71–80. [CrossRef]
41. Lin, S.; Liu, S.; Lu, R.; Ye, Z.; Wang, X.; Wang, J. Spatial and temporal characteristics of relationship between urban compactness and land application efficiency in Guangxi Zhuang Autonomous Region during 2003–2018. *Bull. Soil Water Conserv.* **2021**, *41*, 300–309. [CrossRef]
42. Hoekveld, J. Time-space relations and the differences between shrinking regions. *Built Environ.* **2012**, *38*, 179–195. [CrossRef]
43. Cao, X.; Liu, Y.; Li, T.; Liao, W. Analysis of spatial pattern evolution and influencing factors of regional land use efficiency in China based on ESDA-GWR. *Sci. Rep.* **2019**, *9*, 520. [CrossRef] [PubMed]
44. Xu, W.; Xu, Z.; Liu, C. Coupling analysis of land intensive use efficiency and ecological well-being performance of cities in the Yellow River Basin. *J. Nat. Resour.* **2021**, *36*, 114–130. [CrossRef]
45. Tone, K. A slacks-based measure of efficiency in data envelopment analysis. *Eur. J. Oper. Res.* **2001**, *130*, 498–509. [CrossRef]
46. Tone, K. A slacks-based measure of super-efficiency in data envelopment analysis. *Eur. J. Oper. Res.* **2002**, *143*, 32–41. [CrossRef]
47. Cai, X.; Liang, Y.; Huang, Z.; Ge, J. Spatiotemporal pattern and coordination relationship between urban residential land price and land use intensity in 31 provinces and cities in China. *PLoS ONE* **2021**, *6*, e0254846. [CrossRef]
48. Jiang, H. Spatial–temporal differences of industrial land use efficiency and its influencing factors for China's central region: Analyzed by SBM model. *Environ. Technol. Innov.* **2021**, *22*, 101489. [CrossRef]
49. Yu, H.; Yang, J.; Sun, D.; Li, T.; Liu, Y. Spatial responses of ecosystem service value during the development of urban agglomerations. *Land* **2022**, *11*, 165. [CrossRef]
50. You, H.; Yang, J.; Xue, B.; Xiao, X.; Li, X. Spatial evolution of population change in northeast China during 1992–2018. *Sci. Total Environ.* **2021**, *776*, 146023. [CrossRef]
51. Cen, Y.; Yan, Y.; Zhang, P.; Zhang, Y. Analysis on the coordination of urban compactness and land use intensity under the background of new-type urbanization: A case study of Henan Province. *J. Henan Univ. Nat. Sci.* **2019**, *49*, 282–293, 302. [CrossRef]
52. Eraydin, A.; Ozatagan, G. Pathways to a resilient future: A review of policy agendas and governance practices in shrinking cities. *Cities* **2021**, *115*, 103226. [CrossRef]