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Tight spaces, strong cities: The resilience payoff of urban compactness

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ABSTRACT

This study investigates the critical role of urban compactness in enhancing economic resilience, a topic of growing importance in light of increasing urbanization and external shocks. Using data from Chinese cities spanning 2010–2020 the study develops an urban compactness index based on fractal geometry and nighttime light data. Panel analysis results reveal a significant positive impact of compactness on economic resilience. Robustness checks focusing on sample issues and endogeneity confirm the core finding. Moreover, the impact of compactness is driven by industrial agglomeration, improved land use efficiency, and reduced public fiscal burden. The effect varies by city size and economic development level, with less developed cities benefiting more from compact planning. This study enhances the understanding of how spatial form influences urban resilience and provides policy recommendations for strengthening resilience through compact urban development strategies.

1. Introduction

The COVID-19 pandemic caused an unprecedented global economic shock, with global GDP declining by approximately 3.5 % in 2020, resulting in 114 million job losses and the elimination of 225 million full-time positions (ILO, 2021; IMF, 2021). This large-scale disruption underscores the need for cities to develop resilience—the capacity to absorb external shocks and rapidly restore stability, which is widely applied across various fields (Holling, 1973; Reggiani et al., 2002; Chelleri et al., 2015; Meerow et al., 2016). However, within economics, this concept crystallizes into "economic resilience," which denotes the capacity of an economic system not only to swiftly restore its functions in the face of internal and external shocks but also to achieve sustained development through innovation and structural adjustments amidst crises (Martin and Sunley, 2015). Under the circumstances of intensifying globalization and growing market uncertainties, the investigation of economic resilience not only advances our comprehension of how cities maintain stable economic growth in dynamic contexts, but also offers substantive theoretical frameworks and actionable policy insights for urban governance (Adger et al., 2005; Birkmann, 2013).

Except for traditional factors such as industrial structure, technological innovation, and human capital, urban spatial form could also influence urban economic resilience (Martin and Sunley, 2015; Di Caro and Fratesi, 2018; Xu et al., 2025). The compactness of cities, the structural attribute encompassing elements like functional zoning, transportation networks, and land use efficiency, represents a crucial dimension of spatial form (Dehghani et al., 2022). Past research has largely focused on the environmental impacts of urban compactness. On one hand, compact cities tend to promote public transit and preserve the ecological gradient, which helps reduce greenhouse gas emissions and mitigate encroachment and thereby enhance urban resilience (Elmqvist et al., 2013; Meerow et al., 2016). On the other hand, high-density development may compress urban green spaces, wetlands, and other ecological areas, potentially exposing systemic vulnerabilities during extreme weather events (Neuman, 2005; Davoudi, et al., 2012). Beyond these environmental considerations, compact urban layouts are also hypothesized to facilitate agglomeration economies, improve industrial diversification, optimize resource use, and enhance public service provision (Simmie and Martin, 2010; Hamidi et al., 2015; Mouratidis, 2019; Yao et al., 2022). This suggests that urban compactness is likely to have significant implications for economic resilience as well; however, empirical evidence on the relationship between urban compactness and economic resilience remains limited, particularly in rapidly urbanizing developing countries.

Over the past several decades, the booming global economy has spurred rapid urban expansion that often outpaces both population and

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industrial growth. This phenomenon has led to urban sprawl and over-development, resulting in reduced urban density and inefficiencies in land use and infrastructure (Ewing et al., 1997; Deng and Huang, 2004; Frenkel and Ashkenazi, 2008; Bhatta et al., 2010; Garcia-López, 2012; Zhao et al., 2018; Zhou et al., 2022). China offers a unique case for examining these dynamics; over the past twenty years, the growth rate of urban land in China has been about 1.7 times that of its population, indicating a clear decline in urban compactness. This raises important research questions: How does urban compactness affect economic resilience, and can compact spatial planning help cities recover more quickly from economic disruptions?

This study investigates the role of urban compactness in enhancing economic resilience by analyzing data from 311 Chinese cities spanning 2010–2020. By developing a novel urban compactness index based on fractal geometry and nighttime light data, we provide a more precise measure of spatial form. Through a robust panel data analysis, including two-way fixed effects and IV approaches, we rigorously examine the impact of compactness while addressing potential endogeneity. Our findings demonstrate a significant positive relationship between urban compactness and economic resilience, with key drivers including industrial agglomeration, improved land use efficiency, and reduced public fiscal burdens. Importantly, the study reveals that less developed cities benefit more from compact planning strategies. This research builds on the works of Harari (2020) by not only advancing the methodological approaches to measuring compactness but also by exploring the underlying mechanisms that link compact urban planning to enhanced economic resilience. Through this empirical investigation, we contribute to the broader discourse on urban sustainability and provide policy recommendations that are particularly relevant for cities undergoing rapid urbanization.

2. Theoretical development and research hypotheses

2.1. Definition and measure of urban compactness

The concept of a "compact city" was first raised by Dantzig and Saaty (1973) as a framework for evaluating urban spatial form. Urban compactness generally refers to the degree of spatial intensification in urban form, characterized by high-density development, mixed land use, and efficient transportation networks aimed at curbing urban sprawl. Scholars primarily define compactness through two key dimensions: physical compactness, which focuses on spatial density metrics such as population density and built-up area intensity (Salov and Semerikova, 2024; Mehrotra et al., 2024); and functional integration, which emphasizes the diversity of land-use patterns and the co-location of residential, commercial, and public service facilities (Chin et al., 2024; Efeoglu et al., 2024). To quantify urban compactness, some scholars have relied on typological measurements. For instance, Yao et al. (2022) characterized urban compactness using three independent variables: population density, boundary restrictions, and road density. Similarly, Shi et al. (2016) employed 20 indicators across five dimensions (land use, economy, population, infrastructure, and public services) and applied an entropy method for calculation. While these methods provide a comprehensive evaluation of compactness, they are susceptible to subjectivity and randomness in the selection of indicators and weight calculations, resulting in single-value conclusions that often lack economic significance.

In response to these limitations, some scholars have adopted morphological methods to measure urban compactness more intuitively. For example, Schwarz (2010) used the area of the minimum enclosing circle, the longest perimeter length, and density gradients to represent the compactness. Harari (2020) calculated a disconnection index by computing the average Euclidean distance between any two points within a given polygon; a lower disconnection index indicates a more concentrated urban footprint, thereby reflecting higher compactness, which is intuitive and objective. Therefore, this paper refers to Harari's method and uses fractal geometry principle and night light data to measure the urban compactness at the morphological level.

Using the quantitative methods outlined, numerous studies have explored the costs and benefits of compact versus dispersed urban development. From an environmental standpoint, compact cities promote walkability, reducing reliance on cars and lowering greenhouse gas emissions. High-density layouts and centralized utilities enhance energy efficiency, while limiting urban sprawl preserves green spaces and farmland. In contrast, dispersed urban designs ease city center congestion and noise, with potential ecological benefits such as buffer zones for water bodies and green spaces (Bettencourt and West, 2010; European Commission, 2013; Angel et al., 2011; Kern, 2023; European Environment Agency, 2020). Socially, compact urban areas often concentrate public services effectively and foster strong community interaction, but higher density can drive up housing costs and exacerbate social inequities by limiting peripheral or low-income groups' access to central resources. Meanwhile, dispersed layouts help mitigate affordability pressures and offer quieter, greener living environments (Ewing and Hamidi, 2015; UN-Habitat, 2016; Acolin and Wachter, 2017).

At the urban economic level, Xu et al. (2019) discovered an inverted U-shaped relationship between urban compactness and economic development, suggesting the existence of an optimal level of compactness. On one hand, population and industrial agglomeration facilitate knowledge spillovers and economies of scale, high-density urban structures can significantly lower transportation costs, compact urban planning enhances land use efficiency, mitigates resource misallocation (Glaeser and Gottlieb, 2009; Mahriyar and Rho, 2014; Ewing and Hamidi, 2015). On the other hand, excessively compact cities may face multiple challenges, for example, high population density drives up housing costs rapidly, exacerbated by imbalances in land supply and demand (Hsieh and Moretti, 2019); internal congestion intensifies competition, significantly raising production and operational costs for businesses (Brueckner and Sridhar, 2012); spatial constraints further limit the scale and expansion capabilities of businesses, hindering economic growth and innovation (Cheshire and Hilber, 2008).

2.2. Definition and measure of urban economic resilience

The term "resilience" originates from physics, denoting the resistance of a material to deformation under stress, or the ability of a system to return to its original state following disturbance (Holling, 1973). Reggiani et al. (2002) was the first to introduce the concept of "resilience" in spatial economics, defining it as an economic system's capacity to withstand external shocks or return to a steady state. Martin and Sunley (2015), adopting an evolutionary perspective, further classified economic resilience into four components: resistance, recovery, adaptation, and renewal. As the theory of urban economic resilience has advanced, measurement approaches have been categorized into process-based single indicators and state-based multi-indicators. The former includes models such as Martin et al. (2016) shock cycle models based on sensitivity index methods and Simmie and Martin (2010) post-disaster economic resilience measurement model based on anticipated growth trajectories. In contrast, multi-indicator approaches primarily use analytic hierarchy processes, fuzzy evaluation methods, factor impulse response, or entropy weighting methods to calculate economic resilience indices. Compared to multi-indicator measurements, single-indicator calculations are generally simpler, more reliable, and possess clearer economic significance, making them particularly well-suited for causal inference. (Giannakis and Bruggeman, 2020)

Unlike engineering resilience in physics, economic resilience is predominantly treated as the dependent variable in empirical research. Numerous studies have investigated the factors influencing urban economic resilience. For example, Tang et al. (2023) and Giannakis and Bruggeman (2017) found that industrial specialization and diversification significantly affect urban economic resilience through agglomeration effects and synergistic effects. Furthermore, Pang et al. (2023) demonstrated that technological innovation aids cities in adjusting their industrial structures during recovery periods, thereby generating re-employment opportunities and enhancing economic resilience. Xiao et al. (2024) argued that the development of the digital economy can boost urban resilience by optimizing industrial layouts, promoting industrial upgrading, and accelerating the establishment of digital platforms. Ezcurra and Rios (2019), in his analysis of governmental quality across European regions from 2008 to 2010, found that regions characterized by lower corruption, superior public services, and stronger rule of law were less adversely affected during recessions and exhibited quicker recovery rates.

2.3. Impact of urban compactness on economic resilience

The relationship between urban compactness and urban economic resilience is complex, involving factors such as labor markets, industrial structure, resource efficiency, and social capital (Hamidi et al., 2015; Lee et al., 2015; Mouratidis, 2019). Many scholars agree that moderate levels of compactness play a crucial role in enhancing economic resilience, as it facilitates economic benefits such as improved resource allocation and agglomeration economies. (Sharifi, 2019).

Moderate urban compactness is widely recognized for promoting agglomeration economies, which are essential for economic resilience. According to agglomeration theory, geographic concentration of businesses, industries, and labor creates opportunities for faster job matching, shared services, and enhanced knowledge spillovers (Marshall, 1890). These benefits contribute to the city's ability to quickly adapt to external shocks and maintain productivity in the face of disruptions (Hamidi and Ewing, 2015). Compact urban planning facilitates proximity between economic actors, leading to gains in efficiency and competitiveness (Hamidi et al., 2015). In this way, compactness helps cities capitalize on the agglomeration of production factors, leading to more resilient urban economies. Furthermore, evolutionary economic geography emphasizes adaptability as a critical factor in economic development (Hamidi and Ewing, 2015). Cities with diverse industrial structures and continuous technological innovation are better positioned to respond to external shocks, providing greater economic vitality and resilience (Duranton and Puga, 2004; Bristow and Healy, 2018).

However, excessive urban compactness can lead to certain challenges such as crowding effects and negative externalities (Neuman, 2005). High-density developments often correlate with elevated population-weighted exposure to air pollutants, since compact cities tend to have higher emission density per unit area. This spatial concentration of emissions intensifies localized environmental impacts (Martilli, 2014; Schindler and Caruso, 2014; Yuan et al., 2017). Moreover, as urban compactness increases, cities may face exacerbated congestion and rising housing costs (Li et al., 2019). Despite these concerns, most cities, especially those in developing regions, have not reached levels of over-compactness. In practice, the benefits of compact development (agglomeration advantages, resource efficiency, and reduced sprawl) frequently outweigh the potential downsides, thus contributing to greater economic vitality and resilience (Glaeser and Kahn, 2004).

Hence, this study proposes the following hypothesis:

H1. : Increased urban compactness is expected to enhance urban economic resilience.

2.4. Mechanisms of urban compactness on economic resilience

Compact urban planning influences economic resilience through several key mechanisms. These mechanisms are involved with the agglomeration of industries and labor, land use efficiency, and public fiscal capacity.

First, industrial agglomeration refers to the geographic clustering of businesses, services, and infrastructure within a specific area. This concentration encourages collaboration, accelerates innovation, and enhances knowledge spillovers (Bristow and Healy, 2018). Firms located in close proximity to one another can quickly absorb and apply new technologies, driving productivity and competitiveness. Moreover, agglomeration economies reduce production costs by enabling firms to share infrastructure and supply chains, thus enhancing their ability to weather economic downturns (Glaeser, 2010).

Second, labor agglomeration works in tandem with industrial agglomeration. As industries cluster in compact urban areas, they attract a substantial workforce, which in turn stimulates the development of surrounding services such as housing, transportation, and retail (Duranton and Puga, 2004). Labor agglomeration increases market diversity and job matching efficiency, helping to reduce unemployment rates during economic downturns. Furthermore, social networks that develop within dense urban settings can serve as informal support systems, helping individuals cope with crises and fostering economic resilience (Raco and Street, 2012; Autor et al., 2013; Liu et al., 2024)

Third, compact cities promote land use efficiency, which directly enhances resilience. By encouraging higher-density development, cities can optimize the use of land and reduce the spread of urban sprawl (Ewing and Hamidi, 2015). Efficient land use conserves resources, minimizes ecological impact, and ensures that more urban areas remain viable during economic shocks (Yan et al., 2020). Moreover, compact urban design reduces dependency on peripheral areas, creating more sustainable development patterns and protecting non-renewable land resources (Andreoni and Duriavig, 2013).

Lastly, public fiscal capacity is a crucial factor in resilience. Compact urban planning reduces the need for extensive infrastructure investment, as higher-density developments allow governments to provide services more efficiently. When public fiscal resources are used more effectively, cities can allocate more funds towards counter-cyclical policies, such as providing unemployment benefits, stimulating demand, or supporting struggling industries during economic downturns (Auerbach and Gorodnichenko, 2012). Higher public revenue, derived from more efficient land use, can also support social welfare programs, reducing inequality and enhancing social stability in times of crisis (Dolls et al., 2012; McKay and Reis, 2016).

Based on these mechanisms, the following hypotheses are proposed:

H2. : Urban compactness enhances urban economic resilience by promoting industrial and labor agglomeration.

H3. : Urban compactness enhances urban economic resilience by improving land use efficiency.

H4. : Urban compactness enhances urban economic resilience by reducing public fiscal burdens.

3. Empirical setup

3.1. Model setting

To empirically investigate the impact of urban compactness on economic resilience, this study specifies the following model,

$$RESILIENCE_{it} = \alpha + \beta\, COMPACT_{it} + \boldsymbol{X}\gamma + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

where the dependent variable $RESILIENCE_{it}$ denotes the degree of economic resilience in city i at year t. $COMPACT_{it}$ is the key explanatory variable measuring the level of urban compactness. $\boldsymbol{X}$ is a vector of control variables at the city level that may influence economic resilience, such as the city's population size, human capital, fixed capital investment, and openness to foreign capital. α is the constant term. μ_i and υ_t are city- and time-fixed effects, respectively, used in all specifications to control for the unobservable characteristics affecting a city's resilience degree that vary only at the city level or over time. ε_{it} is the idiosyncratic error term. While considering that there may be heteroscedasticity across cities and correlation within and/or between cities, for comparison purpose, this study will also report the "Parks-Kmenta" type FGLS (Parks, 1967; Kmenta, 1986) estimation results for the baseline model.

The coefficient of interest is β, capturing the effect of urban compactness on economic resilience. Considering that *COMPACT* is a negative indicator, a higher *COMPACT* suggests that the city is less compact. Thus, a negative and statistically significant β would suggest that higher levels of compactness are associated with greater resilience, consistent with the hypothesis that compact urban planning promotes agglomeration economies and more efficient use of resources. The overall empirical roadmap of our study is shown in Fig. 1.

3.2. Variable construction

(1) Economic resilience (*RESILIENCE*): Given the limitations of multi-indicator measurements, such as causal ambiguity and inconsistent indicator weights, this study adopts a single indicator method. Referring to the sensitivity index of Martin et al. (2016), this study quantifies the adaptability of the economic system in response to external shocks:

$$RESILIENCE = \frac{(Y_t^R - Y_{t-1}^R)/Y_t^{R-1} - (Y_t^N - Y_{t-1}^N)/Y_{t-1}^N}{|(Y_t^N - Y_{t-1}^N)/Y_{t-1}^N|} \quad (2)$$

where $(Y_t^R - Y_{t-1}^R)/Y_t^{R-1}$ represents the growth rate of the city's per capita GDP, and $(Y_t^N - Y_{t-1}^N)/Y_{t-1}^N$ denotes the national per capita GDP growth rate, serving as the baseline. A ratio greater than zero indicates strong resilience, with higher values signifying greater resilience. In robustness check, per capita GDP is replaced by employment rate, and changes in employment rate serve as a proxy for urban economic resilience.

Fig. 2 illustrates the distribution of economic resilience in Chinese cities between 2010 and 2020. Economically developed cities such as Beijing, Tianjin, Shanghai, Hangzhou, Shenzhen, Chongqing, and Wuhan ranked among the top, with resilience indices exceeding 15, significantly above the national average. Overall, urban economic resilience across China demonstrated general improvement from 2003 to 2022, with city clusters in the Beijing-Tianjin region, the Yangtze River Delta, and the Pearl River Delta maintaining a leading position. The central and southern regions exhibited substantial growth, while northeastern regions experienced relative decline.

(2) Urban compactness (*COMPACT*): This study references the works of Angel et al. (2010) and Harari (2015), using Chinese administrative vector data alongside NPP-VIIRS-like nighttime light datasets to measure urban compactness through a single indicator. Nighttime light data effectively captures stable illumination within administrative areas, and averaging this light over a year generates annual nighttime light data (Yi et al., 2014). Initially, the data was resampled at a pixel resolution of 500 m, with the highest light value utilized for processing, thus

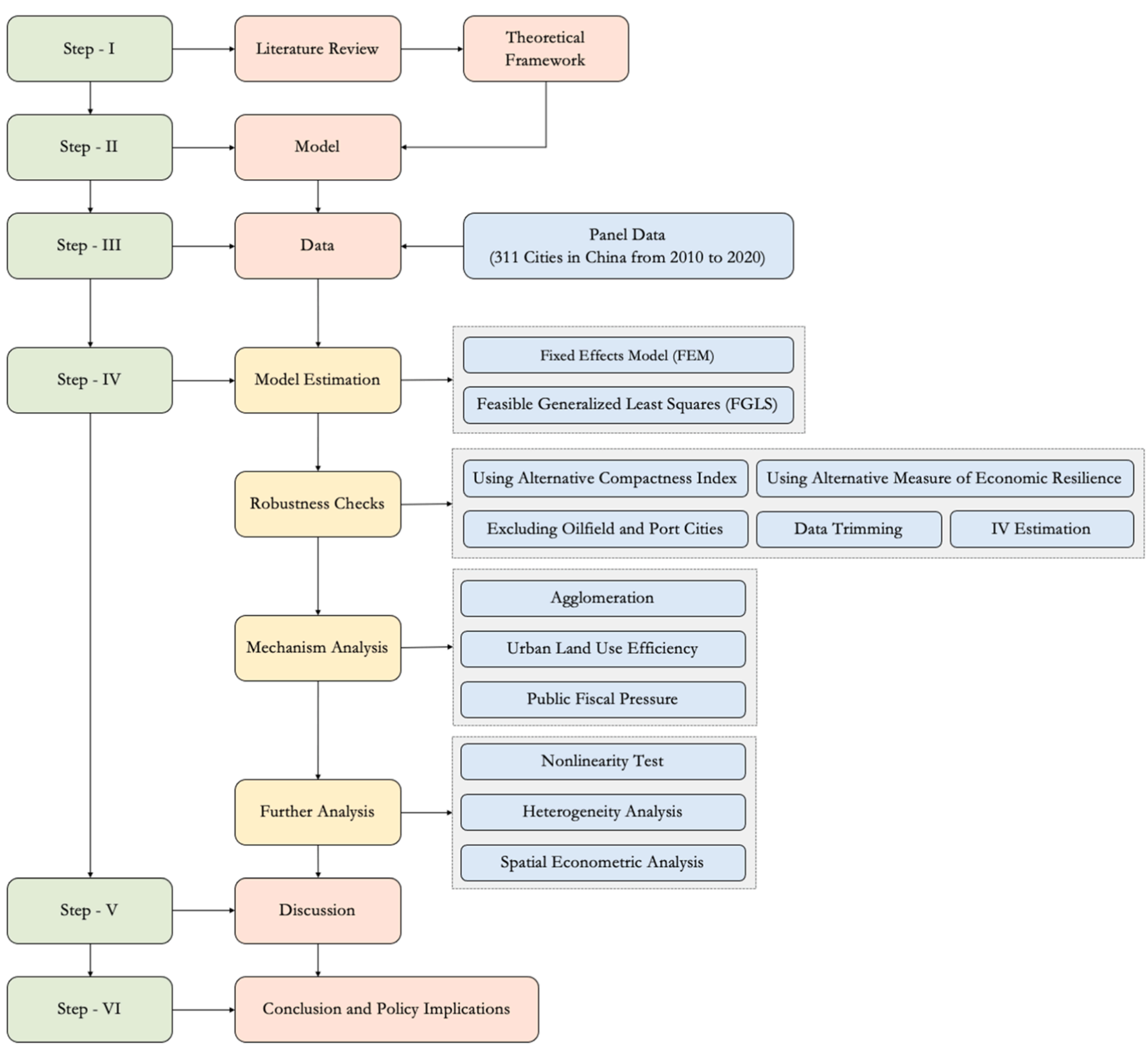

Fig. 1. Roadmap of the research design and methodology.

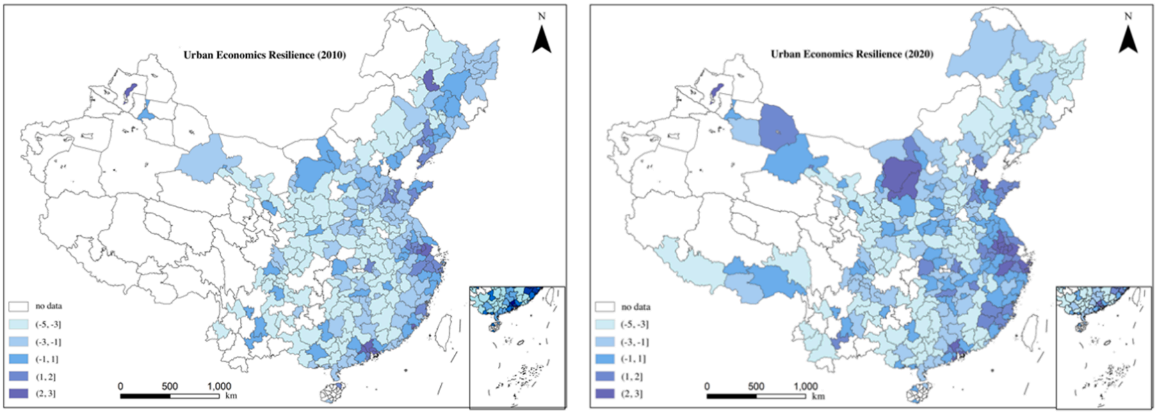

Fig. 2. Spatial distribution of economic resilience in 2010 and 2020.
Note: These two figures were produced based on the standard map with the approval number GS (2022) 1873 downloaded from the standard map service website of the Ministry of Natural Resource, with no modifications made to the base map.

eliminating outlier pixels. Temporal continuity was then applied to correct the data and exclude sudden pixel changes. Given the extensive non-urbanized land within administrative districts, the urban area was determined using a light threshold. Tan (2015) analyzed China's urbanization process from 1992 to 2012 using nighttime light data, concluding that a light intensity of 30–50 DN (Digital Number) effectively differentiates urban from rural areas. Similarly, Li et al. (2007) compared urbanization processes in China and India, finding the 30 DN light threshold to possess strong applicability. Considering China's recent economic development and energy consumption levels, this study adopts a light threshold of over 40 DN to define urban areas, with a 30 DN threshold utilized for robustness checks.

Angel et al. (2010), utilizing fractal geometry and geography, proposed ten indicators for measuring urban compactness. Building on this framework, Harari (2020) calculated the average and squared distances of all points within a city to the central point as proxy indicators for urban expansion and compactness. This study calculates the ratio of the average distance between all points in urbanized areas that meet the light threshold to the square root of the city's area, thereby defining the urban compactness indicator. The specific formula is:

$$Compact = \frac{\sum_{1 \le i < j \le r} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{r(r-1)\sqrt{area}/2} \tag{3}$$

where (x, y) represent the coordinates of grid points within the city, and if a city contains r grids, the total number of grid distances is $r(r-1)/2$. By averaging these distances and dividing by the square root of the area, we yield the urban compactness value.

Fig. 3 shows a map of Beijing's urbanized area in 2020. The left figure uses a light threshold of 30 DN for robustness checks, while the right figure uses a 40 DN threshold for baseline regression. Considering that some cities are composed of multiple geometries, we only calculate the largest contiguous built-up area. After identifying the urbanized areas of each city, the compactness of each city was calculated using Eq. (3). Non-urbanized areas such as farmland, wasteland, water bodies, and forests were excluded from the compactness calculation, thereby providing a more accurate reflection of travel costs for most residents and their accessibility between different areas.

Fig. 4 displays two types of diagnostic plots from running a simple regression of economic resilience on urban compactness, controlling for city and year fixed effects. (i) the partial residual plot, also known as a component-plus-residual plot (Larsen and McCleary, 1972); and (ii) partial-regression leverage plot or added-variable plot (Belsley et al., 2005). Both plots provide some evidence of a positive correlation between urban compactness and economic resilience. It should be noted that these scatterplots are merely preliminary analyses aimed at exploring the linear relationship between compactness and resilience while teasing out potential confounding variables such as city and year fixed effects, they provide no additional information about the causal relationship between compactness and resilience. In the empirical analysis as follows, this study will examine the causal effect of urban compactness on economic resilience.

(3) Control variables: (i) Total urban population (*POP*): This variable reflects the overall size of the city. Larger populations and spatial scales are typically associated with stronger resilience and enhanced crisis management capabilities (Wang et al., 2023). (ii) Number of university

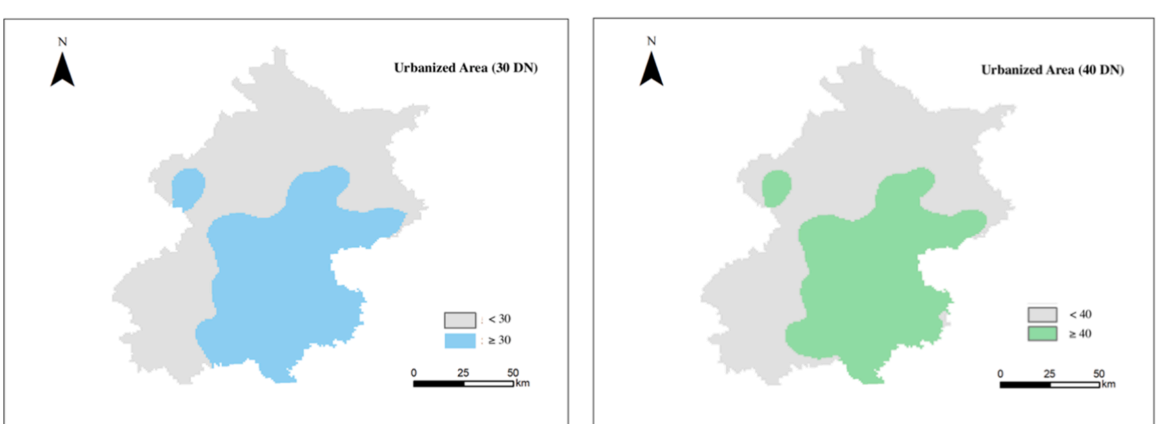

Fig. 3. Urbanized areas of Beijing in 2020 (30 DN and 40 DN).

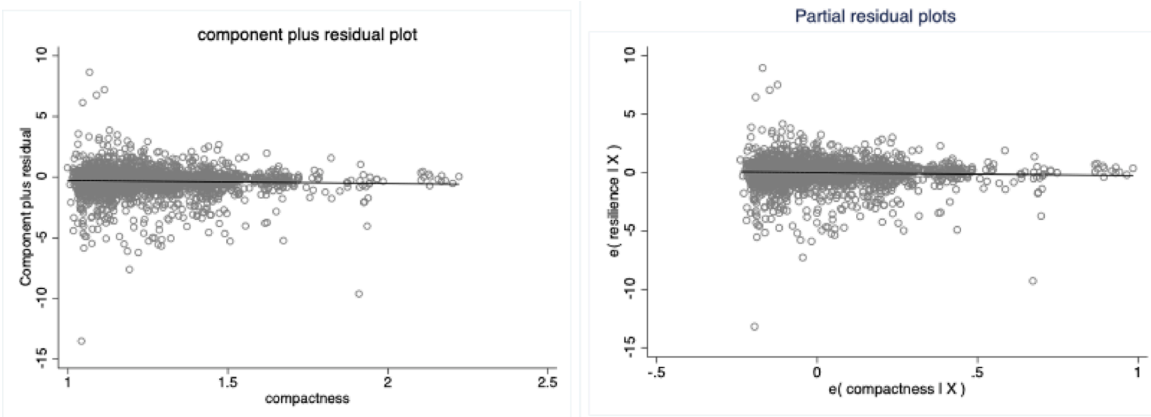

Fig. 4. Partial residual and partial regression average plots.

students (*EDU*): This metric serves as an indicator of human capital within the city. A higher concentration of human capital fosters innovation and adaptability, facilitates economic recovery and industrial upgrading, and bolsters the city's capacity to withstand risks (Cappelli et al., 2021; Zhou and Qi, 2023). (iii) Year-end total fixed capital investment (*FIX*): This variable measures the extent of fixed capital in the city. Fixed capital investment is critical for infrastructure development and technological advancement, thereby augmenting the city's ability to respond to external shocks and enhancing overall economic resilience (Miao and Xiao, 2024). (iv) Actual utilized foreign investment amount (*OPEN*): This ratio assesses the city's level of economic openness. Increased levels of openness are linked to increased technological innovation and industrial upgrading, which contribute to the city's resilience against environmental and economic disturbances (Zhang and Luo, 2022). (v) Year-end balance of loans from financial institutions (*FIN*): This measure evaluates the influence of financial factors on economic resilience. Greater financial openness and effective financial reform policies substantially enhance urban economic resilience by promoting technological innovation and supporting industrial upgrading (Jiang et al., 2024).

3.3. Data sources and descriptive statistics

This study uses panel data from 311 prefecture-level and above cities in mainland China from 2010 to 2020. Micro-level city data comes from the *China City Statistical Yearbook*, macro-level data from the *China Statistical Yearbook*, and remote sensing data from the Resource and Environmental Sciences Data Center of the Chinese Academy of Sciences (www.resdc.cn) and the National Earth System Science Data Center (www.geodata.cn). Missing values within this data were filled in using an interpolation technique that was based on the averages from the adjacent years. Table 1 outlines each variable's definition, data source, mean, standard deviation, and variance inflation factor (VIF), providing a clear view of how each variable is measured and confirming that multicollinearity is not a major concern.

4. Results

4.1. Baseline results

Before conducting an in-depth analysis, this study performs the Hausman test (Hausman, 1978) to compare a fixed effects model (FEM) and a random effects model (REM), concluding that the FEM is the preferred one. Table 3 shows the baseline regression results. Columns (1) and (2) apply the FEM, with column 1 taking into account solely the principal compactness index variable and column 2 incorporating all control variables. Columns (3) and (4) mirror the setups of columns (1)

Table 1
Descriptive statistics.

Variable	Definition	Data source	Mean	Std. dev.	VIF
RESILIENCE	Urban economics resilience	China City Statistical Yearbook (CSY)	−0.103	0.701	
COMPACT	Urban compactness index	NPP-VIIRS-like' nighttime light dataset	1.223	0.170	1.03
POP	Total urban population (ten thousand)	CSY	440.214	312.194	2.89
EDU	Number of university students (number of university students per 10,000 people)	CSY	163.393	216.309	1.76
FIX	Year-end total fixed capital investment (ten thousand yuan)	CSY	1432.556	1533.175	4.31
OPEN	Actual utilized foreign investment amount (ten thousand dollar)	CSY	9.275	21.456	4.06
FIN	Year-end balance of loans from financial institutions (ten thousand yuan)	CSY	2347.042	4954.059	3.28

and (2), respectively, but present the FGLS estimation outcomes for comparison purpose.

As observed in columns (1) and (2) of Table 2, the coefficients on the compactness variables (*COMPACT*) are positive and statistically significant at the 1 % level. When comparing columns (3) and (4) with columns (1) and (2), the estimates using the FGLS model, which accommodates for panel heteroscedasticity and serial correlation, bears the same positive signs and the estimated compactness effects are larger in magnitude. These findings suggest a significant influence of urban compactness on economic resilience, implying that a more compact urban form significantly enhances the economic resilience of a city, supporting and confirming hypothesis H1. Specifically, the coefficient on compact ($\beta = -0.205$, $t = -1.72$) in column 4 reveals that one standard deviation decrease in compactness index (1.223) would increase urban economic resilience by 0.251 (= 0.205 × 1.223), which is

Table 2
Baseline results.

	FEM model		FGLS Model	
COMPACT	−0.264 ***	−0.204 **	−0.264 **	−0.205 *
	(−2.63)	(−2.03)	(−2.25)	(−1.72)
POP		0.0003 ***		0.0003 ***
		(4.60)		(5.26)
FIX		0.00006**		0.00004
		(2.45)		(1.02)
EDU		0.00008		0.0003 ***
		(0.59)		(5.80)
OPEN		0.003		0.00003
		(0.02)		(0.03)
FIN		−0.000002		−0.000002
		(−0.65)		(−1.02)
Constant	0.200	0.002	0.200	0.001
	(1.59)	(0.01)	(1.36)	(0.01)
Hausman test statistic		15.88[0.003]		
LR test statistic for heteroscedasticity				2.35[0.000]
Wooldridge test statistic for autocorrelation				2.76[0.966]
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Obs.	3421	3421	3421	3421
R^2	0.125	0.107	0.125	0.107

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

approximately 36 % (= 0.205/0.70) of its own standard deviation.

4.2. Robustness checks

4.2.1. Using alternative compactness index

To assess the robustness of our key finding, this study uses an alternative calculation of the compactness index, as suggested by Tan (2015). Specifically, we adjusted the nighttime light intensity threshold to 30, acknowledging that the determination of the urbanized area is pivotal in measuring urban compactness. This adjustment allows for a better understanding of how urban compactness is defined and operationalized within the context of our analysis.

The results, presented in column (1) of Table 3, indicate that the marginal impact of the newly calculated compactness index aligns closely in both magnitude and direction with that derived from the baseline definition. For instance, the effect size associated with the alternative measure is −0.205 in column (1) of Table 3, compared to −0.204 in column (2) of Table 2. This consistency in findings suggests that our primary conclusions regarding the relationship between urban compactness and economic resilience are robust to variations in the compactness index measurement.

4.2.2. Using alternative measure of economic resilience

In column (2), we substitute the dependent variable to further explore the effects of economic shocks on urban dynamics. Economic shocks not only influence a city's per capita GDP but also exert a more immediate impact on employment levels. For instance, during the COVID-19 pandemic, shifts in employment rates were observed to occur prior to changes in GDP, highlighting a sharp decline in employment in the short term. Following He et al. (2023), we adjusted our measure of

Table 3
Robustness checks.

	Replace *COMPACT*	Replace *RESILIENCE*	Excluding oilfield and port cities	Data trimming	IV results
COMPACT	−0.205 **	−0.227 ***	−0.156 *	−0.155 *	−0.273 **
	(−2.03)	(−2.94)	(−1.72)	(−1.82)	(−2.41)
POP	0.0003 ***	0.0003 ***	0.0003 ***	0.0003 ***	0.0003 ***
	(4.59)	(4.60)	(4.86)	(4.89)	(4.39)
FIX	0.00004 **	0.00004 **	0.00005 ***	0.00005 ***	0.00004 **
	(2.40)	(2.39)	(2.93)	(3.07)	(2.07)
EDU	0.0003 ***	0.0003 ***	0.0003 ***	0.0004 ***	0.0003 ***
	(3.17)	(3.17)	(3.57)	(4.16)	(2.67)
OPEN	0.00003	0.00003	0.001	0.001	−0.0002
	(0.03)	(0.02)	(0.70)	(0.66)	(−0.13)
FIN	0.000002	0.000004	0.000002	0.000003	0.000004
	(0.63)	(0.65)	(0.48)	(0.59)	(1.05)
Constant	0.302	1.002 ***	−0.06	−0.10	0.048
	(0.50)	(7.69)	(−0.52)	(−0.89)	(0.33)
Covariates	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
CD F statistic					220.96[9.08]
KP F statistic					12.18[9.08]
Hansen J test stat.					4.48[0.11]
Obs.	3421	3421	3013	3352	3421
R^2	0.125	0.147	0.149	0.131	0.063

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

urban economic resilience to utilize employment rates instead of GDP. This adjustment allows for a comparative analysis of the variations in city employment rates against the national average employment rate changes.

The results are shown in column (2) of Table 3, where the coefficient for urban compactness remains significantly negative and, notably, exceeds the magnitude observed in the baseline regression. This result indicates that employment rates are more responsive to economic shocks compared to per capita GDP, suggesting that urban compactness plays a crucial role in shaping employment resilience in the face of economic disturbances. This result may also imply that urban compactness enhances a city's ability to adapt to and recover from economic shocks more effectively than previously understood through GDP alone.

4.2.3. Excluding oilfield and port cities

In column (3), we present the regression results following the exclusion of oilfield and port cities from our analysis. These specific urban areas, characterized by the bright flames from oil wells and the intense illumination from lighthouses in port cities, often exhibit nighttime light intensity levels significantly higher than those found in typical urbanized regions. This discrepancy can complicate the accurate identification of nighttime light data, as noted by Dai et al. (2017). To ensure the integrity of our findings, we removed 14 oilfield cities and 23 port cities based on data pertaining to petroleum extraction and water transportation.

The regression outcomes, displayed in column (3) of Table 3, reveal that the coefficient for urban compactness remains basically consistent with that observed in the baseline regression. This stability suggests that the excessive nighttime illumination associated with oilfields and ports did not compromise the fitting accuracy of our nighttime light data in relation to urbanized areas. Consequently, our conclusions regarding the impact of urban compactness on economic resilience remain robust, even when these outlier cities are excluded.

4.2.4. Data trimming

In column (4), we present the regression results following the trimming of the top and bottom 5 % of the sample. The cities within the top 5 % in terms of economic resilience predominantly include capital cities or first-tier cities. These locations typically benefit from advanced levels of development, strong policy support, and a pronounced siphoning effect that attracts resources and talent. In contrast, the bottom 5 % consists largely of cities situated in remote or mountainous regions, characterized by poor accessibility, high poverty rates, and significant resource constraints. These outliers do not represent typical urban environments and may distort the overall analysis.

The regression analysis reveals that the coefficient for urban compactness remains significantly negative, aligning with our previous findings. This robustness check confirms that our conclusions are not driven by extreme cases, but rather reflect a genuine relationship between urban compactness and economic resilience across a more representative sample.

4.2.5. Instrumental variable (IV) estimation

While the baseline regression results align with the hypotheses, potential endogeneity issues may arise due to the complex relationship between urban compactness and economic resilience. Unobserved factors, such as local government policies or cultural attributes, could influence both urban compactness and economic resilience, leading to biased estimates. Additionally, reverse causality may be a concern; for example, cities facing economic shocks might accidentally change their urban planning strategies, affecting their compactness. Moreover, omitted variable bias could occur if key determinants of economic resilience, such as social capital or historical context, are excluded from the model.

Therefore, we use the IV approach to deal with endogeneity. The selected instrumental variables are topographic relief (*SLOPE*), rebar prices (*STEEL*), and the policy to determine urban development boundaries (*POLICY*). These three instrumental variables are relatively exogenous to urban economic development while being closely related to urban compactness, making them suitable for our analysis. The rationale is as follows: (i) topographic relief significantly influences urban boundary expansion. Uneven terrain restricts urban sprawl and encourages cities to adopt smart growth strategies (Chettry and Surawar, 2020). Moreover, a city's surface features are exogenous, difficult to modify, and exhibit a low correlation with economic development levels. (ii) Higher construction costs promote more compact urban development. Increased construction expenses lead developers and local governments to favor high-density residential and commercial areas, thereby minimizing the need for peripheral land expansion (Ewing and Hamidi, 2015). Since construction costs are challenging to measure directly, this study uses rebar prices as a proxy, as rebar is a crucial material in reinforced concrete construction and its price remains relatively consistent nationwide. (iii) Past urban planning policies have also influenced urban compactness (Glaeser and Kahn, 2004). Since 2013, the Chinese government has implemented a policy that determine urban development boundaries, prohibiting land development outside designated areas. Initially piloted in 14 cities and later expanded nationwide, we use the presence of urban development boundaries as a dummy variable, assuming these boundaries promote compactness. Data for these variables are manually collected from spatial planning documents at the provincial level.

The IV regression results in column (5) in Table 3 suggest several key findings. First, the IV estimates of the compact coefficients using three sets of IVs are generally robust to the baseline (FEM/FGLS) specifications when focusing on urban resilience. This indicates that the use of instrumental variables helps to address potential endogeneity issues in the relationship between compactness and urban resilience. Second, the estimated association between compact and urban resilience is found to be considerably strengthened when the compact variable is instrumented, as evidenced by a larger coefficient than in the FEM/FGLS setup. Third, the estimation results are shown to be reliable and not challenged by weak instruments or overidentification issues, as judged by corresponding diagnostic tests.

4.3. Mechanism analysis

In Section 2, we proposed three theoretical mechanisms linking urban compactness to economic resilience and demonstrated a significant positive relationship between them in Section 4. This section aims to empirically test some of these channels.

Following Balli and Sørensen (2013), we introduce interaction terms and rewrite the baseline regression model as:

$$RESILIENCE_{it} = \gamma_0 + \gamma_1 COMPACT_{it} + \gamma_2 M_{it} + \gamma_3 COMPACT_{it} \times M_{it} + \boldsymbol{X}\delta + \lambda_i + \lambda_t + \in_{it} \quad (4)$$

where M_{it} represents the mediation variables—the channels through which urban compactness influences economic resilience. If the sign of the interaction term coefficient γ_3 is the same as that of the explanatory variable coefficient γ_1, it indicates that the channel enhances the positive effect of urban compactness on economic resilience. Each variable is defined as follows:

(1) Agglomeration (*LQ_IND* and *LQ_POP*): Yao et al. (2024) posits that diversified industrial agglomeration, particularly in service industries, mitigates risks and fosters knowledge spillovers, thus enhancing a city's self-regulation and recovery capacity, ultimately improving economic resilience. Industrial agglomeration is quantified using the location quotient of the secondary industry, represented as $LQ\_IND_{it} = (e_{ijt}/e_{jt})/(E_{it}/E_t)$, where e represents the region's total output, E represents the national total

output, and j represents the secondary industry. Alternatively, Liu et al. (2024) argues that population agglomeration significantly bolsters economic resilience through positive spatial spillover effects. Following Cao et al. (2023), population agglomeration is measured by $LQ\_POP_{it} = (P_{it}/P_{nt})/(A_{it}/A_{nt}) = (P_{it}/A_{it})/(P_{nt}/A_{nt})$, where P represents the population, A represents land area, i represents the city, and n represents the nation.

(2) Urban land use efficiency (*EFFICIENCY*): Ma et al. (2023) contends that enhancing land use efficiency minimizes resource waste and environmental degradation, thus improving urban sustainability and resilience to risks. Efficient land use also augments land productivity. As described by Song et al. (2022), this study evaluates land use efficiency through the input-output ratio, $EFFICIENCYit = (VAS_{it} + VAT_{it})/LAND_{it}$, where $LAND_{it}$ represents the city i's urban construction land area at year t, and the added value of secondary and tertiary industries is represented by *VAS* and *VAT*, respectively.

(3) Public fiscal pressure (*DEBT*): Bo et al. (2017) found that increased urban sprawl correlates with heightened infrastructure and public service costs, affecting governmental behavior during disasters. Following Gong et al. (2022), public fiscal pressure is quantified as $DEBT_{it} = (EXP_{it} - REV_{it})/REV_{it}$, where EXP_{it} represents the fiscal expenditure of city i at year t, and REV_{it} represents the fiscal revenue of city i at year t.

Table 4 presents the regression results. Column (1) indicates that industrial agglomeration is a key factor for enhancing economic resilience in compact cities, as indicated by a significantly negative coefficient for the interaction term. Compact urban spaces typically imply high-density industrial environments, which significantly improves firms' innovation capabilities through knowledge spillovers and competition (Guo et al., 2023). This technological innovation enables companies to pursue new growth opportunities, particularly in challenging business climates. Furthermore, industrial agglomeration facilitates the integration of resources and collaboration among firms, allowing them to jointly mitigate industry risks through network effects (Rosenthal and Strange, 2004). In addition, by achieving economies of scale, industrial agglomeration reduces production costs, which enhances productivity and competitiveness, ultimately equipping firms to navigate economic crises (Delgado et al., 2014).

Table 4
Mechanism analysis.

	LQ_IND	LQ_POP	EFFICIENCY	DEBT
COMPACT	−0.224 ** (−2.21)	−0.234 ** (−2.32)	−0.347 *** (−3.26)	−0.243 ** (−2.22)
LQ_IND	0.002 ** (2.01)			
COMPACT × LQ_IND	−0.002 ** (−2.06)			
POP		0.001 (1.33)		
COMPACT × POP		−0.002 (−1.35)		
EFFICIENCY			0.011 *** (4.08)	
COMPACT × EFFICIENCY			−0.000007 *** (−4.09)	
DEBT				−0.017 (−1.54)
COMPACT × DEBT				0.025 * (1.72)
Covariates	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Obs.	3421	3421	3421	3421
R^2	0.171	0.178	0.153	0.127

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

Column (2) indicates that compact cities enhance economic resilience by fostering population agglomeration. The interaction term coefficient for population agglomeration is significantly negative. Regions with higher population densities exhibit greater efficiency in matching supply with demand. During external shocks, increased labor mobility helps to reduce unemployment and bolsters economic resilience (Duranton and Puga, 2004). Moreover, areas characterized by population agglomeration benefit from robust community networks, where social members often establish cooperative relationships. In times of economic hardship, these close social ties can offer psychological support, material assistance, and job referrals, thereby mitigating the effects of economic shocks (Aldrich, 2012).

Column (3) highlights that compact cities enhance economic resilience through improved land use efficiency. Specifically, high-density, mixed-use urban layouts not only conserve land resources and promote sustainable development but also optimize resource allocation (Ewing and Hamidi, 2015). Effective sustainable land use planning protects the ecological environment, reduces pollution, and enhances urban livability, creating a healthy and stable conditions for economic development (Wang and Zhang, 2024). Improved land use efficiency allows limited land resources to be maximally used for productive activities, thereby increasing overall urban productivity and resource utilization, ultimately bolstering economic resilience (Ciccone and Hall, 1993).

Column (4) reveals a significantly positive interaction term coefficient between urban compactness and government debt burden, although the coefficient for urban compactness itself is not significant. Compact urban development diminishes the demand for infrastructure construction and maintenance, lowers public service costs, and reduces public fiscal expenditure, all of which contribute to enhanced urban economic resilience. Sufficient fiscal reserves and stable income sources enable governments to maintain essential public spending during economic downturns, thereby providing a stable socio-economic environment (Alesina et al., 2015). Furthermore, robust public fiscal capacity facilitates counter-cyclical policies, such as tax reductions, increased social security spending, and expanded infrastructure investment, which are essential for fostering economic recovery (Auerbach and Gorodnichenko, 2012).

4.4. *Further analysis*

4.4.1. *Nonlinearity test*

In Section 2, we highlighted that while moderate compactness can enhance economic resilience, excessive compactness may have the opposite effect. Specifically, moderate levels of population agglomeration facilitate knowledge spillovers and foster technological innovation, creating a talent pool that effectively responds to economic shocks. Conversely, excessively high population density can result in environmental degradation, rising housing costs, and various social challenges, complicating government management efforts.

To test for the potential nonlinear relationship between urban compact form and the economic resilience index, this study applies three different approaches: (1) adding a quadratic term for the compactness variable in the baseline model, (2) conducting a panel quantile regression (Koenker, 2004), and (3) applying a panel threshold model (Hansen, 1999). Table 5 presents the results of the nonlinearity analysis using three different methodologies: quadratic form (column 1), quantile regression (column 2), and threshold regression (column 3). The findings indicate that compact urban form significantly affects economic resilience, as evidenced by the negative coefficient of −0.119 in the quadratic model. Although the negative coefficient of −0.219 for the quadratic term (*COMPACT2*) suggests that the urban compactness does not necessarily always enhance economic resilience, the p-value is not significant. The quantile regression results, derived using the bootstrap method with 20 replications, reveal that the impact of urban

Table 5
Nonlinearity analysis.

	Quadratic form	Quantile regression	Threshold regression
COMPACT	0.339	−0.119 **	
	(0.38)	(−2.14)	
COMPACT2	−0.219		
	(−0.69)		
[0.988, 1.053]			−0.333
			(−0.73)
[1.053, 2.222]			−0.859 *
			(−1.70)
Covariates	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Obs.	3421	3421	3421
R^2	0.126	0.104	0.065

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

compactness remains positive, and the magnitude is bigger. Furthermore, the negative coefficients across various quantiles indicate that the effects of compactness vary depending on the level of economic resilience. Specifically, the thresholds reveal significant effects at point: 1.053 (in the range of [1.053, 2.222]). This reinforces the idea that the positive effect of urban compactness on economic resilience is robust, with no significant non-linear trend observed.

4.4.2. Heterogeneity analysis

In the context of China, the impact of urban compactness on economic resilience is likely to differ across city subgroups due to the distinct regional characteristics and uneven development patterns across the country. In this section, we aim to test these heterogeneity effects through five subgroup regressions by city area, population size, city development level, secondary sector development, and tertiary sector development.

4.4.2.1. City area. Columns 1 and 2 of Table 6 present the subgroup regression results, where city samples are divided based on whether the city's built-up area is higher than the national average. The results show that the coefficients for urban compactness are significantly negative in both large and small cities, though the impact is slightly stronger in small cities. This suggests that compactness benefits economic resilience across different city sizes, and while smaller cities do see marginally greater benefits, the effect is not substantially different between the two groups. This finding is in line with the existing literature, such as Galster (2001) and Tsai (2005) and which emphasize that urban compactness is not merely a function of geographic size but is more closely related to land-use patterns and development density. Larger cities do not necessarily exhibit lower levels of compactness, and land-use efficiency or the degree of population and industrial agglomeration can remain high even in geographically expansive cities. Thus, the positive effect of compactness in large cities, as observed empirically, could be driven by efficient land use and dense urban cores, mitigating the potential downsides of sprawl.

4.4.2.2. City scale and development level. Columns (3) and (4) of Table 6 show that cities with larger populations exhibit no significant impact of urban compactness on economic resilience, while the effect is significant in cities with smaller populations. Similarly, columns (5) and (6) reveal that cities with higher GDP experience less benefits from compactness than cities with lower GDP. In developed cities like Beijing, Shanghai, or Shenzhen, where urban sprawl and population density are already high, the benefits of compactness may be limited, as these cities already face challenges such as congestion, environmental degradation, and high living costs. However, compact urban development still plays a role in enhancing economic resilience by optimizing land use and facilitating the concentration of economic activities. On the other hand, in some China's interior or underdeveloped cities, compact urban development is expected to have a stronger impact by efficiently concentrating resources, reducing travel times, and fostering localized agglomeration economies, which boost productivity and help reduce vulnerabilities to external shocks.

4.4.2.3. Sectoral development. Columns (7)-(10) of Table 6 show the results of the subgroup regressions, which classify the sample of cities according to whether their secondary or tertiary sectors account for a higher share of GDP than the national average. The results show that urban compactness has a stronger impact on economic resilience in cities where the secondary industry is more developed. The higher coefficients indicate that compactness amplifies the benefits of agglomeration economies in these cities, where industrial activities benefit from proximity due to reduced transportation costs, shared infrastructure, and spillovers of technology and innovation (Ellison, 2010). This

Table 6
Heterogeneity analysis.

	City area		City scale and development level			
	Large	Small	Large pop. size	Low pop. size	High GDP	Low GDP
COMPACT	−0.179 **	−0.343 **	−0.208	−0.308 ***	−0.216 **	−0.249 **
	(−2.07)	(−2.22)	(−1.63)	(−2.81)	(−2.04)	(−2.11)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	1693	1728	1703	1718	1661	1760
R^2	0.087	0.151	0.073	0.158	0.178	0.131
	Develop. (secondary)		Develop. (tertiary)			
	High	Low	High	Low		
COMPACT	−0.287 **	−0.231 **	−0.203 **	−0.289 **		
	(−2.30)	(−2.27)	(−2.00)	(−2.29)		
Covariates	Yes	Yes	Yes	Yes		
Year FE	Yes	Yes	Yes	Yes		
City FE	Yes	Yes	Yes	Yes		
Obs.	1702	1719	1702	1719		
R^2	0.141	0.162	0.142	0.173		

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

supports the argument that manufacturing-heavy cities exhibit greater resilience when compact urban layouts facilitate logistical efficiencies and industrial clustering (Dehghani et al., 2022). In contrast, the results in columns (9) and (10) show that the impact of compactness is lower in cities where the tertiary sector is more developed. This reflects the changing nature of service-based economies, where remote work, digital tools, and knowledge exchange reduce reliance on physical proximity (Allen et al., 2015). As a result, compact urban development does not contribute as significantly to resilience in service-driven cities.

4.4.3. Spatial econometric analysis

To empirically test whether urban compactness affects the economic resilience of neighboring cities, we apply the spatial Durbin model (Anselin, 1988), a widely used framework in spatial econometrics for analyzing the direct and indirect effects of the compactness variable on neighboring cities. The model extends the traditional spatial lag and spatial error models by incorporating both the spatial lag of the dependent variable and the spatial lag of the independent variables, allowing for a comprehensive examination of spatial spillover effects (Elhorst, 2014). The model is specified as follows,

$$RESILIENCE_{it} = \alpha + \rho W \times RESILIENCE_{it} + \mathbf{Z}\theta + W \times \mathbf{Z}\xi + \mu_i + \nu_t + \varepsilon_{it} \tag{5}$$

where ρ captures the spatial dependence of the dependent variable (i.e., economic resilience), Z denotes a set of explanatory variables, including urban compactness; W is the spatial weight matrix that defines the spatial structure of the cities, in this practice, this study will specify three types of spatial weight matrices for comparison: geographic (the geographic distance between cities), economic (absolute difference in per capita GDP between cities), and economic-geographical (a combination of geographic distance and economic distance). Other terms are defined as previously described.

Table 7 provides the spatial Durbin model results. Across all three spatial weight matrices used, both the direct and indirect (spillover) effects are significantly negative, with the direct effect slightly higher than the spillover effect. Specifically, the coefficients for the direct effects range from −0.299 to −0.216 ($p < 0.05$), respectively, indicating that compact urban development improves resilience through mechanisms such as agglomeration economies, reduced transportation costs, and shared infrastructure (Ellison, 2010). The indirect or spillover effects are particularly notable in the economic-geographical and economic matrices. Significant positive spillovers (−0.223 and −0.127, $p < 0.05$) suggest that compactness in one city boosts the economic resilience of neighboring cities, especially when they share economic linkages. This supports the theoretical expectation that knowledge spillovers, trade relationships, and infrastructure connectivity extend beyond city borders, benefiting the surrounding region (Duranton and Puga, 2004; Glaeser, 2010). In contrast, the economic matrix shows a weaker spillover effect, implying that geographic proximity is more crucial than pure economic closeness for these resilience gains (Rodríguez-Pose, 2011).

It is also worth mentioning that there is a positive spatial autocorrelation in economic resilience among cities, suggesting that resilient cities can positively influence neighboring areas by providing market demand, shared infrastructure, and governance models. This supports regional coordination, where cities with stronger resilience help nearby areas withstand external shocks through shared resources and public services (Emerson et al., 2012; Martin and Sunley, 2015).

Table 7
Spatial Durbin model results.

	Geographical distance	Economic distance	Economic geographical distance
ρ	0.289 ***	0.132 ***	0.342 ***
	(9.65)	(4.39)	(11.40)
COMPACT	−0.277 ***	−0.197 ***	−0.212 ***
	(−4.24)	(−3.94)	(−4.05)
W*COMPACT	−0.026	−0.184 ***	−0.079 **
	(−0.66)	(−4.61)	(−1.97)
Covariates	Yes	Yes	Yes
Direct effects	−0.299 ***	−0.216 ***	−0.251 ***
	(−3.84)	(−3.85)	(−4.19)
Indirect effects	−0.127	−0.223 ***	−0.191 ***
	(−1.50)	(−3.22)	(−2.73)
Total effects	−0.427 ***	−0.439 ***	−0.442 ***
	(−4.19)	(−5.70)	(−5.53)
Obs.	3421	3421	3421
Log-likelihood	−228.46	−195.28	−172.39

Notes: Corresponding robust t-statistics are reported in parentheses. Critical values are reported in brackets. *** , **, and * denote significance at the 1 %, 5 % and 10 % levels, respectively.

5. Discussion

5.1. Discussion on the nexus between variables

Our study confirms the complex impact of urban compactness on economic resilience—a relationship that has often been overlooked in previous research on economic resilience. Based on empirical tests using a sample of Chinese cities, we find that more compact cities tend to exhibit stronger economic resilience, meaning they recover more quickly from adverse external shocks. Some studies from developed countries have suggested that excessively high urban density may lead to congestion effects and negative externalities, potentially weakening economic resilience (Storper and Scott, 2016). However, given that Chinese cities generally face the issue of urban sprawl, with urban population density having steadily declined over the past two decades, the tipping point from moderate to excessive compactness may not yet have been reached.

The mechanisms by which urban compactness influences economic resilience primarily involve agglomeration effects, land use efficiency, and public finance pressure. A compact city, characterized by higher population and business densities, leverages agglomeration effects to generate economies of scale, a larger labor pool, and knowledge spillovers, thereby enhancing its ability to withstand risks. More rigorous land use planning can reserve available land for future development, enabling governments to stimulate economic recovery by developing new districts or towns during crises. Moreover, compact cities facilitate more efficient public fiscal investments, reducing wastage in infrastructure and public services in sprawling areas and lowering public construction expenditures; as a result, during downturns, city governments have sufficient fiscal reserves to implement proactive policies such as tax cuts and increased welfare spending.

Finally, the effect of urban compactness on economic resilience shows significant heterogeneity. Compared to large cities, small and medium-sized, as well as underdeveloped cities, tend to benefit more from compact planning. This is because mega-cities like Beijing and Shanghai already exhibit high population densities and land use efficiencies, limiting the marginal benefits of further compact planning. In contrast, smaller cities often lack sufficient capital and resources for stringent urban planning, and lower land costs coupled with net outflows of population increase the risk of urban sprawl, making enhanced compactness particularly important. Additionally, cities dominated by the secondary sector are more likely to enhance economic resilience through compact planning. Compact urban design can improve logistics efficiency, reduce transportation costs, and promote the clustering of upstream and downstream industries; however, the rise of digital technologies has enabled many service-oriented firms to collaborate remotely and work online, thereby diminishing the potential advantages of compact urban layouts (OECD, 2020).

5.2. Policy and practice recommendations for urban planning

First, the critical role of urban compactness in shaping economic resilience becomes evident, particularly as its effects differ by developmental stage. In smaller and medium-sized cities, prioritizing compact urban development can significantly boost economic adaptability and resource efficiency. When planners promote mixed-use zoning and industrial clustering, infrastructure investments and labor resources become concentrated, which in turn enhances overall productivity and minimizes the inefficiencies associated with urban sprawl. For instance, when residential, commercial, and industrial areas are combined into one compact space, it simplifies transportation and encourages cooperation among different sectors, as shown by spatial clustering models (Glaeser, 2010). Meanwhile, larger cities must carefully navigate the balance between achieving compactness and mitigating potential drawbacks such as congestion or overburdened services; urban planning in these areas should thus emphasize optimizing connectivity and creating infrastructure redundancies to preserve resilience without sacrificing efficiency.

Second, regional collaboration is equally vital for enhancing economic resilience. Shared investments in infrastructure, ranging from intercity transportation networks and utilities to comprehensive emergency response systems, can extend and amplify the benefits of compact urban forms across broader geographic scales. Drawing inspiration from frameworks like the EU's regional cohesion policy (Duranton and Puga, 2004), cities can institutionalize mechanisms for inter-municipal cooperation that allow them to pool resources and mitigate risks collectively. For example, establishing joint authorities to manage infrastructure projects or coordinate disaster management strategies can help reduce redundant efforts while ensuring equitable access to critical services, thereby reinforcing both individual city resilience and broader regional economic stability.

Third, fiscal measures should also play a central role in incentivizing compact growth to align urban development with long-term resilience objectives. Governments are encouraged to introduce tax benefits for high-density, transit-oriented projects as well as subsidies for upgrading public transportation systems, strategies that collectively serve to discourage inefficient sprawl. Initiatives such as density bonuses for developers who integrate affordable housing or green infrastructure into urban cores can stimulate private-sector participation in sustainable planning (Ewing and Hamidi, 2015).

5.3. Contributions and limitations

This study makes several key contributions to the literature. First, it expands the current understanding of how urban spatial form (specifically compactness) affects economic resilience, providing empirical evidence from one of the world's most rapidly urbanizing countries (Briguglio et al., 2009; Pelling, 2010; ; Briguglio, 2016; UN-Habitat, 2016; Tupy et al., 2021). Whereas in the past, the impacts of urban spatial patterns have often been limited to ecological resilience or environmental resilience. Second, it offers a methodological advancement by applying fractal geometry and remote sensing data to create a more precise and intuitive measure of urban compactness. Finally, the study provides practical policy recommendations for urban planners and policymakers in China and other developing countries, where managing urban growth efficiently is critical for fostering sustainable and resilient cities.

While this study introduces novel perspectives and makes substantial contributions, it is not without limitations. On one hand, economic resilience is a multidimensional concept. The sensitivity indices employed in this study predominantly reflect an equilibrium viewpoint, assuming stable states within urban economies and evaluating resilience based on the convergence speed towards economic equilibrium. However, from an evolutionary perspective, scholars such as Folke et al. (2010) define economic resilience as a continuous process of evolution and innovation, challenging the notion of absolute equilibrium states and thereby complicating quantitative assessments. Therefore, further research is needed to clearly delineate how urban economies "resist, recover, adapt, and innovate" in response to external shocks (Martin and Sunley, 2015). On the other hand, it is noted that some cities comprise multiple geometries, yet our analysis focuses solely on calculating the largest contiguous built-up area. However, research suggests that multi-center cities often exhibit greater economic resilience (Ahlfeldt and Pietrostefani, 2021). Their multi-center structures mitigate vulnerabilities in specific regions or economic sectors, facilitating efficient resource utilization through competitive and collaborative dynamics among these centers. This study refrains from considering the impact of multi-center configurations on compactness and resilience indices. Addressing how to scientifically evaluate the compactness of multi-center cities requires deeper consideration to avoid potential overestimations.

6. Conclusion

This study explores the significant role of urban compactness in enhancing economic resilience, using data from 311 Chinese cities from 2010 to 2020. The empirical findings demonstrate that compact urban development contributes positively to resilience through mechanisms such as industrial agglomeration, improved land use efficiency, and reduced public fiscal burdens. These effects are particularly pronounced in less developed cities, and in cities where the secondary sector (manufacturing and industry) dominates. Furthermore, the spillover effects of compactness extend to neighboring cities, especially when they share economic linkages.

Several policy implications can be drawn from our findings. Compact urban planning should be strengthened to maintain smart growth and improve the urban growth boundary system, reducing blind and disorderly urban expansion to enhance economic resilience. In addition, clear functional zoning within cities should also be implemented to encourage industrial and labor agglomeration in compact cities. Furthermore, cooperation between central cities and surrounding underdeveloped cities should be strengthened to promote regional integration, achieve resource sharing, and facilitate complementary development.

While our study offers invaluable insights into the complex dynamics of urban spatial form and economic resilience, its primary emphasis on Chinese settings denotes certain boundary conditions. Considering that a body of evidence from the United States and the European Union suggests that excessive compactness is detrimental to urban economic development, when this turning point will occur in China still requires further research. Going forward, future studies should expand to cover untouched factors, more accurate measurement methods of compactness and economic resilience, more dimensional evaluation of urban form, and comparative analysis across countries.

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CRediT authorship contribution statement

Haoyu Lian: Writing – original draft, Software, Methodology, Formal analysis. **Shuning Kong**: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis. **Yihua Yu**: Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of Competing Interest

None.

Data availability

Data will be made available on a reasonable request.

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