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Research article

On the impact of the digital economy on urban resilience based on a spatial Durbin model

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Abstract: Based on panel data from 31 provinces in China between 2011 and 2020, we empirically studied the impact of the digital economy on urban resilience using fixed-effects models, threshold-effects models and spatial Durbin models. Our research findings indicate that (1) the development of the digital economy has a significant positive impact on the enhancement of urban resilience; (2) the promotional effect of the digital economy on urban resilience varies significantly across different regions; (3) the promotional effect of the digital economy on urban resilience exhibits a typical double-threshold characteristic due to the different levels of development in digital financial inclusion and (4) the digital economy has a positive spillover effect on the urban resilience of surrounding areas. Therefore, we should actively promote the development of the digital economy and digital financial inclusion, making the digital economy a new driving force for promoting urban resilience.

Keywords: digital economy; urban resilience; digital financial inclusion; threshold-effects model; spatial Durbin model
Mathematics Subject Classification: 62P20, 62P25

1. Introduction

1.1. Background

The rise and prosperity of the digital economy have presented new fields, new tracks and new dynamics for the development of the economy and society, and it is becoming an important force leading social development [1–3]. The digital economy, supported by digital technology, has unique penetration, innovation and integration advantages. It not only effectively enhances the economic links and the flow of resource factors between cities, but it can also become a powerful tool for cities to resist risk crises [4,5]. Faced with crises and challenges at home and abroad, we should actively seize and make good use of the opportunity window of digital economic development, making the digital economy a new driving force for promoting urban resilience.

1.2. Related research

Since Don Tapscott put forward the concept of the digital economy in 1996, the research on the digital economy in academia has been continuously expanded, and it can be mainly summarized into two categories. The first is the measurement of the digital economy. It includes using single-index measurement methods such as national economic accounting, the value-added method, and digital economy satellite account construction and building a comprehensive index evaluation system [6] according to the connotation of the digital economy. Second is the economic effect of the digital economy. At the macro level, the digital economy can promote high-quality development and increase total factor productivity [7], as well as improve the quality and efficiency of labor, knowledge, management, capital and technology factors [8]. At the meso-level, the digital economy can promote industrial technology upgrade and improve industrial competitiveness [9]. At the micro level, the digital economy can reduce transaction costs, alleviate information asymmetry [10] and motivate firms to sustain innovation and improve risk-taking [11].

Resilience originated in engineering, and the concept of resilience was first applied to ecology by the ecologist Holling in 1973 [12]. Sometime after, resilience appeared in urban design and planning, and urban resilience was born. Alberti et al. defined urban resilience as the ability and level to absorb and resolve changes in a city before the reorganization of a set of structural and process changes [13], and Desouza and Flanery defined urban resilience as the capacity to absorb, adapt and cope with changes in urban systems [14]. The research on urban resilience mainly focuses on constructing and measuring evaluation index systems. Regarding evaluation index system construction, Cutter et al. [15] constructed an urban resilience assessment index system from five aspects: economic, social, infrastructure, institutional and community capital. Suárez et al. [16] selected five indicators from the social-ecological system perspective to construct an urban resilience framework. Wang et al. [17] constructed an indicator system from economic, social, ecological and engineering resilience. Chen et al. [18] constructed an urban resilience evaluation system based on the “economic-social-ecological-engineering” framework. In terms of measurement methods, scholars have commonly measured the level of urban resilience by performing AHPs [19], entropy methods [17] and the TOPSIS method [18].

1.3. Contributions

Although Jing [20] has theoretically expounded on the promotional effect of the digital economy on urban resilience, few scholars have empirically studied the relationship between the digital economy and urban resilience. Digital technology has broken through the bottleneck of resource element flow and greatly improved resource allocation efficiency in various socioeconomic fields. Its powerful innovation and penetration capabilities have enabled the digital economy to penetrate every aspect of the economic and social environment. It is not only a new economic growth point, but it is also an important support for improving urban resilience. Therefore, the development of the digital economy should have a significant promotional effect and a spatial spillover effect on urban resilience building. To this end, based on the research achievements of previous studies, and by using panel data from 31 provinces in China from 2011 to 2020, we first constructed a comprehensive index system of the digital economy and urban resilience. Then, a fixed-effects model was used to investigate the basic relationship between the digital economy and urban resilience. Next, the nonlinear relationship was tested based on the digital financial inclusion development level. Finally, the spatial spillover effect of the digital economy on urban resilience was explored, and corresponding countermeasures are proposed based on the actual development of various regions to provide a valuable decision-making reference for improving urban resilience.

2. Theory and research hypothesis

2.1. Related theory

First, the digital economy, driven by core technologies such as big data, cloud computing, the Internet of Things and blockchain, features interconnectedness and sharing, which can overcome the limitations of time and space [21–26]. It not only enables pre-disaster information acquisition, analysis and warning, but it also enhances post-disaster emergency communication, response and recovery capabilities. Second, digital technology can promote mutual penetration and integration among various systems in the city, optimizing resource allocation and improving operational efficiency, thereby comprehensively enhancing the resistance and resilience of urban systems to risks.

Digital financial inclusion is an extremely important part of the digital economy, and the development of the digital economy is constrained by the level of digital financial inclusion [27–33]. When digital financial inclusion is in its infancy, the infrastructure of digital technology is not yet perfect, and digital technology cannot effectively penetrate various fields of social and economic development, so the promotion of the digital economy to urban resilience is not yet prominent. As digital financial inclusion enters the growth stage, digital technology becomes iteratively upgraded and widely applied. The impact of digital technology on the economy, society and environment begins to deepen, thereby enhancing the promotional effect of the digital economy on urban resilience. When digital financial inclusion tends to stabilize, the scale and benefits of digital technology tend to maximize, and, at this point, the promotional effect of the digital economy on urban resilience is the strongest.

The internet possesses rapid and efficient information transmission capability. Based on the internet, the digital economy not only exhibits strong vitality, but it also overcomes the constraints of geographical distance between regions without being limited by physical space. In addition, the digital technology on which the digital economy relies has strong diffusion and penetration abilities, which not only effectively enhance inter-regional connections, but also improve the spatial correlation of various resource elements within cities. Therefore, it can be seen that the digital economy's impact on urban resilience may have spatial spillover effects.

2.2. Research hypotheses

Based on the relevant theoretical analysis, the following three hypotheses are proposed in this paper.

Hypothesis 1: The digital economy has a positive effect on urban resilience.

Hypothesis 2: The impact of the digital economy on urban resilience exhibits nonlinear characteristics due to differences in the development level of the digital financial inclusion.

Hypothesis 3: Due to spatial spillover effects, the digital economy not only directly impacts the urban resilience of the local area, but it also indirectly impacts the urban resilience of the surrounding areas.

3. Models, variables and data

3.1. Model construction

3.1.1. Benchmark model

Mathematical models and statistical optimization are widely used in engineering, chemistry, physics and other fields [34–36]. We have constructed the following benchmark model to empirically study the impact of the digital economy on urban resilience:

$$UR_{it} = \alpha_0 + \alpha_1 DIGE_{it} + \alpha_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it} ,$$

where *UR* is the explained variable, i.e., urban resilience. *DIGE* is the explanatory variable: digital economy. *Z* is the set of control variables; μ represents individual effects, δ represents time effects and ε is the random disturbance term.

3.1.2. Threshold-effects model

Considering that the impact of the digital economy on urban resilience may have nonlinear characteristics due to the different levels of digital financial inclusion development, we have constructed the following double-threshold effect model by drawing on the threshold regression model proposed by Hansen [37]:

$$UR_{it} = \alpha_0 + \alpha_1 DIGE_{it} \times I(DFI \le \lambda_1) + \alpha_2 DIGE_{it} \times I(\lambda_1 < DFI \le \lambda_2) + \alpha_3 DIGE_{it} \times I(DFI > \lambda_2) + \alpha_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it} ,$$

DFI is the threshold variable: digital financial inclusion development level; λ is the threshold value. $I(\cdot)$ is the indicator function, and I=1 when the condition is satisfied. Otherwise, I=0.

3.1.3. Spatial econometric model

We have constructed the following spatial econometric model to analyze whether the digital economy will impact the urban resilience of the surrounding area.

Spatial autoregressive model (SAR):

$$UR_{it} = \alpha_0 + \rho WUR_{it} + \alpha_1 DIGE_{it} + \alpha_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it}.$$

Spatial error model (SEM):

$$UR_{it} = \alpha_0 + \alpha_1 DIGE_{it} + \alpha_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it},$$

$$\varepsilon_{it} = \rho W \varepsilon_{it} + \upsilon_{it}.$$

Spatial Durbin model (SDM):

$$UR_{it} = \alpha_0 + \rho WUR_{it} + \alpha_1 DIGE_{it} + \eta_1 WDIGE_{it} + \alpha_c Z_{it} + \eta_2 WZ_{it} + \mu_i + \delta_t + \varepsilon_{it},$$

where W is the spatial weight matrix, ρ is the spatial autoregressive coefficient and η_1 and η_2 are the spatial lag term coefficients. The spatial weight matrix used in this paper is the economic distance matrix with the following expression:

$$W = \begin{cases} \dfrac{1}{\left|\overline{Y}_i - \overline{Y}_j\right|}, & i \neq j \\ 0, & i = j \end{cases}.$$

$\overline{Y}_i$ and $\overline{Y}_j$ denote the average values of GDP per capita in regions i and j from 2011 to 2020, respectively.

3.2. Variable description

3.2.1. Explained variable

Urban resilience (*UR*). We refer to the research results of the existing literature [15,17,18,38–40] and divide urban resilience into four types of secondary indicators: economic resilience, social resilience, ecological resilience and infrastructure resilience, whose corresponding various types of tertiary indicators are set in Table 1.

We use the entropy method to calculate the level of urban resilience, which is calculated as follows.

The data were first normalized according to the nature of the indicators.

Positive indicators:

$$y_{ij} = \frac{x_{ij} - min(x_{1j}, x_{2j}, \ldots, x_{nj})}{max(x_{1j}, x_{2j}, \ldots, x_{nj}) - min(x_{1j}, x_{2j}, \ldots, x_{nj})}.$$

Negative indicators:

$$y_{ij} = \frac{max(x_{1j}, x_{2j}, \ldots, x_{nj}) - x_{ij}}{max(x_{1j}, x_{2j}, \ldots, x_{nj}) - min(x_{1j}, x_{2j}, \ldots, x_{nj})}, \quad (i=1,2\ldots,n, \quad j=1,2\ldots m).$$

Then, we calculate the indicator entropy value:

$$e_j = -\frac{1}{ln(n)}\sum_{i=1}^{n}\left\{\frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}} ln \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}\right\} \quad .$$

The final calculation of the overall score is

$$U_i = \sum_{j=1}^{m}\left\{\frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \times y_{ij}\right\} \quad .$$

Table 1. Comprehensive evaluation index system of urban resilience and digital economy.

Tier 1 indicators	Secondary indicators	Tertiary indicators	Nature of indicator
Urban resilience	Economic resilience	Gross regional product per capita (yuan/person)	+
		Share of tertiary sector in GDP (%)	+
		Public revenue as a percentage of GDP (%)	+
		Per capita financial institution deposit balance (yuan/person)	+
		Retail sales of social consumer goods per capita (yuan/person)	+
	Social resilience	Average wage of employees on the job (yuan)	+
		Medical institution beds per 10,000 people (number)	+
		Number of college students per 10,000 people (persons)	+
		Public library collections per 100 people (volumes)	+
		Urban registered unemployment rate (%)	–
	Ecological resilience	Greening coverage rate of built-up areas (%)	+
		Park green space per capita (m^2/person)	+
		Harmless treatment rate for domestic waste (%)	+
		Urban sewage treatment rate (%)	+
		Sulfur dioxide emissions per unit of GDP (tons)	–
	Infrastructure resilience	Gas penetration rate (%)	+
		Daily domestic water consumption per capita (liters)	–
		Public transportation vehicles per 10,000 people (standard units)	+
		Urban road area per capita (square meters)	+
		Length of urban drainage pipes (10,000 km)	+
Digital economy	Internet development	Number of internet users per 100 people (persons)	+
		Computer services and software industry employees accounted for the proportion of urban unit employees (%)	+
		Total telecom businesses per capita (yuan)	+
		Number of cell phone subscribers per 100 people (persons)	+
	Digital financial inclusion development	Digital financial inclusion index	+

Note: The symbol "+" indicates a positive indicator, and "–" indicates a negative indicator.

3.2.2. Explanatory variable

Digital economy development level (*DIGE*). We borrowed the research method of Zhao et al. [6] and used principal component analysis to measure it; the various indicators selected are shown in Table 1. The main steps are as follows. First, the data were standardized by using the Z-score method, and the results of the KMO test and Bartlett's spherical test confirmed that principal component analysis could be performed; then, the principal components were selected according to the cumulative variance contribution rate of 90% principle, and, finally, three principal components were selected to obtain the digital economy principal component scores. The associated test results and tables of total variance explained are respectively shown in Tables 2 and 3.

Table 2. KMO test and Bartlett's test.

KMO value		0.73
Bartlett's sphericity test	Approximate cardinality	1209.075
	df	10
	P	0.000

Note: Principal component analysis can be performed when KMO>0.6 and P<0.05.

Table 3. Table of total variance explained.

Ingredients	Feature Root	Explanation of variance (%)	Cumulative variance explained (%)
1	3.435	68.703	68.703
2	0.972	19.435	88.138
3	0.297	5.947	94.085
4	0.197	3.931	98.015
5	0.099	1.985	100

To facilitate the subsequent study, we normalized the composite digital economy scores calculated via principal component analysis to the [0,1] interval in the following way:

$$DIGE_i = 0.4 \times \frac{dige_i}{max(dige_i) - min(dige_i)} + 0.6 \quad ,$$

where $DIGE_i$ is the standardized digital economy development level, and $dige_i$ is the initial digital economy composite score.

3.2.3. Threshold variable

Digital financial inclusion development level (*DFI*). We selected Peking University's digital financial inclusion index to measure the level of digital financial inclusion development.

3.2.4. Controlled variables

We have selected the following control variables: (1) Economic density (*ECOD*), represented by the logarithm of the ratio of regional GDP to urban land area; (2) Government intervention (*GOV*), measured by the ratio of public fiscal expenditure to GDP; (3) Science and technology level (*TEC*), measured by the proportion of scientific and educational expenditures in public fiscal expenditure; (4) Population size (*POP*), measured by the logarithm of population density.

3.3. Data sources and description

3.3.1. Data sources

We selected data from 31 provinces in China from 2011 to 2020 as panel data. Except for the digital financial inclusion index, they were obtained from the National Bureau of Statistics of China, China Statistical Yearbook, China Environmental Statistical Yearbook, statistical yearbooks and the statistical bulletins of each province.

3.3.2. Data description

Some of the missing data values were filled in using interpolation. The descriptive statistics of each variable are shown in Table 4.

Table 4. Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
UR	310	0.264	0.106	0.097	0.690
DIGE	310	0.600	0.060	0.512	0.912
DFI	310	216.235	97.030	16.220	431.928
ECOD	310	1.327	0.517	−0.438	2.409
GOV	310	0.297	0.210	0.120	1.354
TEC	310	0.183	0.033	0.106	0.256
POP	310	7.872	0.418	6.244	8.669

4. Empirical results

4.1. Benchmark regression

The results of the benchmark regression are shown in Table 5. The F-test, and Hausman test, selected the fixed-effects model. All regressions use robust standard errors for clustering at the provincial level to overcome heteroskedasticity and autocorrelation problems.

Table 5. Benchmark regression results.

Variable	OLS (1)	FE (2)	FE (3)
DIGE	1.545***	0.702***	0.609***
	(11.593)	(11.105)	(5.628)
ECOD	−0.018	0.150***	0.094***
	(−0.673)	(10.587)	(4.934)
GOV	−0.016	0.341***	0.235***
	(−0.600)	(3.663)	(2.883)
TEC	0.626***	0.068	0.282**
	(4.179)	(0.544)	(2.060)
POP	−0.004	−0.133***	−0.086***
	(−0.099)	(−8.791)	(−4.925)
Constant	−0.718**	0.580***	0.305**
	(−2.092)	(3.932)	(2.366)
Province fixed	NO	YES	YES
Time fixed	NO	NO	YES
N	310	310	310
R^2	0.824	0.940	0.960

Note: t-values in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, same as in the following table.

According to Table 5, the impact of the digital economy on urban resilience is significantly positive at the level of 1%, indicating that the development of the digital economy has a significant positive effect on enhancing urban resilience, thus verifying Hypothesis 1 proposed in Section 2. For controlled variables, a higher economic density strengthens a city’s ability to withstand economic risks, so increasing economic density can enhance urban resilience. Government intervention is positively correlated with urban resilience, meaning that government intervention can reasonably allocate resources, improve the structure of various urban systems, increase resistance and recovery capabilities to external risks and thus improve the level of urban resilience. The scientific and technological development level can improve urban productivity, promote comprehensive development of the urban economy and society and thus enhance urban resilience. The size of the population has a significant negative effect on urban resilience, indicating that a larger population size can cause crowding effects, trigger various social problems, affect the regular operation of urban systems and thus hinder the enhancement of urban resilience.

4.2. Heterogeneity test

Due to certain differences in the levels of economic development, industrial structure, ecological and environmental protection and infrastructure services in different regions, this may lead to relatively obvious differences in both the level of development of the digital economy and the development of urban resilience in each region. Therefore, based on Chinese regional planning standards, we divided 31 provinces into three regions, namely, east, central and west, and analyzed the heterogeneity of the impact of the digital economy on urban resilience in different regions based on different samples. The regression results are shown in Table 6.

Table 6. Heterogeneity test results.

Variable	Eastern region	Central region	Western region
DIGE	0.646***	0.471**	0.176*
	(3.729)	(3.013)	(2.000)
ECOD	0.123***	0.105***	0.007
	(4.016)	(3.593)	(0.356)
GOV	0.412**	0.156	0.072
	(2.414)	(1.110)	(1.627)
TEC	0.414*	0.406***	0.241***
	(2.052)	(4.069)	(4.036)
POP	−0.117***	−0.101**	−0.006
	(−4.027)	(−3.099)	(−0.449)
Constant	0.506	0.466	0.015
	(1.623)	(1.851)	(0.137)
Province fixed	YES	YES	YES
Time fixed	YES	YES	YES
N	120	90	100
R^2	0.957	0.984	0.981

From the regression results in Table 6, there is significant variability in the effect of the digital economy on promoting urban resilience across regions. Among them, the digital economy has the most significant effect on promoting urban resilience in the eastern region. Because the development of the digital economy in the eastern region started earliest and has sufficient financial support and talent supply, digital technology has been widely used and integrated with traditional industries to a higher degree, fully releasing the digital economy dividend. Therefore, the digital economy has the most obvious effect on promoting the resilience of cities in the eastern region. In contrast, the digital economy in the western region started to develop the latest, so the digital economy has the weakest effect on promoting urban resilience in the western region.

4.3. Robustness tests

4.3.1. Substitution of explanatory variable

We used the digital financial inclusion development level (*DFI*) to replace the level of digital economy development. The regression results are presented in column (1) of Table 7. The regression coefficient of the digital economy on urban resilience remains significantly positive, which is consistent with the conclusions reached in Section 4.1.

4.3.2. Winsorizing the sample

Considering that there may be individual outliers in the sample, we winsorized the sample at 1% before regression, as presented in column (2) of Table 7. The results are still significant at the 1%

level, indicating that the model is robust.

4.3.3. Instrumental variables method

To address the possible endogeneity problem of the model, we drew on Guo et al. [41]. We use the product of the lagged one-period digital economy development level and the national digital economy development level (the average of the digital economy development levels of 31 provinces) as the instrumental variable and apply 2SLS to the regression. The results in column (3) of Table 7 show that the effect of the digital economy on urban resilience remains significantly positive at the 1% level after accounting for the endogeneity of the model. Meanwhile, the LM and Wald F statistics significantly reject the original hypotheses of "insufficient identification of instrumental variables" and "weak instrumental variables", respectively, indicating that the instrumental variables were reasonably chosen.

Table 7. Robustness test results.

Variable	Substitution of explanatory variables (1)	Winsorizing the sample (2)	Instrumental variables method (3)
DFI	0.001***		
	(8.083)		
DIGE		0.551***	1.002***
		(4.138)	(6.735)
Control variable	YES	YES	YES
Constant	0.631***	0.284*	0.217
	(4.825)	(1.743)	(1.003)
Kleibergen-Paap rk LM statistics			6.457
			[0.011]
Kleibergen-Paap rk Wald F-statistic			180.186
			{16.38}
Province fixed	YES	YES	YES
Time fixed	YES	YES	YES
N	310	310	279
R^2	0.964	0.956	0.989

Note: p-values within [ ]. Within { } are critical values at the 10% level of the Stock-Yogo weak identification test.

5. Threshold effect of digital financial inclusion

5.1. Test of threshold effect

We constructed a threshold-effects model to explore the nonlinear impact of the digital economy on urban resilience for different digital financial inclusion indexes. The results of the threshold-effects test in Table 8 show a double threshold for the impact of the digital economy on urban resilience, with thresholds of 272.923 and 344.764, respectively.

Table 8. Results of the threshold-effects test.

Number of thresholds	F-value	P-value	Threshold value	95% confidence interval	Number of BS
Single	63.53***	0.000	272.923	[264.166, 274.334]	500
Double	29.52***	0.004	344.764	[328.752, 347.806]	500
Triple	21.55	0.382			500

Note: Because the triple threshold did not pass the significance test, the threshold values and confidence intervals are not shown.

5.2. Regression analysis of threshold effects

According to the test results in Table 8, a double-threshold effect model was used for regression, and the regression results are shown in Table 9.

Table 9. Threshold-effect regression results.

Variable	*DFI* ≤272.923	272.923< *DFI* ≤344.764	*DFI* >344.764
DIGE	0.330***	0.356***	0.391***
	(3.198)	(3.437)	(3.955)
Control variable	YES	YES	YES
Constant	0.426***	0.426***	0.426***
	(3.594)	(3.594)	(3.594)
Province fixed	YES	YES	YES
Time fixed	YES	YES	YES
N	310	310	310
R^2	0.969	0.969	0.969

As shown in Table 9, regardless of the level of the digital financial inclusion index, the digital economy has a significant promotional effect on urban resilience. When the digital financial inclusion index is below the low threshold value of 272.923, the coefficient of the impact of the digital economy on urban resilience is 0.330. When the digital financial inclusion index is between the threshold values of 272.923 and 344.764, the coefficient of the impact of the digital economy on urban resilience is 0.356. When the digital financial inclusion index crosses the high threshold value of 344.764, the coefficient of the impact of the digital economy on urban resilience is 0.391. Therefore, the continuous improvement of the digital financial inclusion index will play an apparent catalytic role in the digital economy's improvement of urban resilience. The above conclusions indicate that regions with different digital financial inclusion indexes can enjoy the dividend of the digital economy and improve their resilience level. However, regions with higher digital financial inclusion indexes will benefit slightly more from the development of the digital economy than regions with lower digital financial inclusion indexes. Thus, Hypothesis 2, proposed in Section 2, is verified. The levels of digital financial inclusion in the eastern, central and western regions range from high to low. Therefore, in the case of the heterogeneity test described in Section 4.2, the digital economy has the strongest promotional effect on urban resilience in the eastern region, while the promotional effect of the digital economy on urban resilience in the central and western regions will gradually diminish.

6. Spatial effect analysis

6.1. Spatial autocorrelation test

We use the global Moran index to test the spatial autocorrelation of both the digital economy and urban resilience via the following formula:

$$Moran's\, I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} ,$$

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n} ,$$

where W_{ij} is the economic distance matrix.

The test results are shown in Table 10.

Table 10. Spatial autocorrelation test.

Year	*UR*		*DIGE*	
	Moran's *I*	z-value	Moran's *I*	z-value
2011	0.398***	4.575	0.257***	3.749
2012	0.398***	4.544	0.256***	3.776
2013	0.400***	4.569	0.282***	3.863
2014	0.408***	4.664	0.263***	3.855
2015	0.402***	4.668	0.262***	3.861
2016	0.413***	4.792	0.265***	3.806
2017	0.411***	4.779	0.271***	3.789
2018	0.407***	4.733	0.290***	3.916
2019	0.404***	4.706	0.305***	4.151
2020	0.398***	4.597	0.312***	4.411

The results in Table 10 show that the digital economy and urban resilience in all 31 Chinese provinces from 2011–2020 are spatially autocorrelated and suitable for analysis based on the spatial econometric models.

6.2. Identification and testing of spatial econometric models

To determine which model would be more suitable for this study, we first conducted an LM test. The Robust LM_error in the LM test did not pass the significance test, while all others passed the 1% significance test. Second, we used LR and Wald tests. The LR and Wald test values for SAR were 13.07 and 13.05, respectively, passing the 5% significance test and indicating that SDM would not degenerate into SAR. The LR and Wald test values for SEM were 17.05 and 17.41, respectively, passing the 1% significance test and indicating that SDM would not degenerate into SEM. All test results are shown in Table 11.

Table 11. Identification and testing of spatial econometric models.

Test	Chi^2	P-value
LM_error	33.585***	0.000
Robust LM_error	0.742	0.389
LM_lag	55.445***	0.000
Robust LM_lag	22.602***	0.000
LR test for SAR	13.07**	0.023
LR test for SEM	17.05***	0.004
Wald test for SAR	13.05**	0.023
Wald test for SEM	17.41***	0.004

6.3. Spatial Durbin model regression analysis

Based on the test results in Table 11, the SDM was used in this work; the regression results are shown in Table 12.

Table 12. SDM regression results.

Variable	Economic distance matrix		
	Direct effect	Indirect effects	Total effect
DIGE	0.414***	0.909***	1.323***
	(3.095)	(2.806)	(4.241)
Control variable	YES	YES	YES
Province fixed	YES	YES	YES
Time fixed	YES	YES	YES
N	310	310	310
R^2	0.342	0.342	0.342
Log-L	976.072	976.072	976.072

The results in Table 12 show that the effects of the digital economy on urban resilience are all significantly positive at the 1% level. It indicates that the digital economy enhances urban resilience in the local area and has a positive spillover effect on the level of urban resilience in the surrounding areas. Hypothesis 3, proposed in Section 2, is tested. Combined with the heterogeneity test in Section 4.2, the economic foundation of the eastern region is better, and the spillover effect of the digital economy is stronger, thus triggering a ripple effect among the eastern regions. Thus, the promotion effect of the digital economy on urban resilience in the eastern region is the strongest. Along with the increase of economic distance, the promotion effect of the digital economy on the urban resilience of surrounding regions shows a marginal decreasing trend, so the regression coefficient and significance level of the digital economy on urban resilience of central and western regions will be weakened appropriately.

7. Conclusions and suggestions

7.1. Conclusions

Based on panel data from 31 provinces in China from 2011 to 2020, we empirically studied the impact of the digital economy on urban resilience and the threshold effect of the level of digital financial inclusion. We have drawn the following four conclusions. First, the digital economy significantly promotes the improvement of urban resilience levels, and this conclusion still holds after robustness tests. Second, in the test of regional heterogeneity, we found that the promotional effect of the digital economy on urban resilience levels varies significantly across regions. The digital economy has the most significant effect on promoting urban resilience in the eastern regions, followed by the central regions and, lastly, the western regions. Third, in the threshold-effects test, we found that regions with different levels of digital financial inclusion indexes can all benefit from the development of the digital economy and improve their own urban resilience levels. However, regions with higher digital financial inclusion indexes can benefit slightly more from the development of the digital economy than those with lower indexes. Fourth, the SDM regression results show that the digital economy has a positive spillover effect on the urban resilience of surrounding areas.

7.2. Suggestions

With the above findings, we make the following suggestions.

First, differences in resource endowment, location conditions and industrial structure mean that the development model and direction of the digital economy cannot be the same in different regions. Therefore, each region needs to explore the development path of the digital economy according to local conditions to avoid digital transformation traps that hinder the healthy development of the digital economy. The recommendation is to make the digital economy a new driving force for resilient urban development.

Second, the development of the digital economy should be based on the industrial base of the digital economy, highlight the policy orientation and give full play to the advantages of resources. Other recommendations are as follows: increase the introduction and cultivation of digital economy enterprises, implement digital economy industrial projects and focus on research and development, design and manufacturing artificial intelligence, intelligent sensors, etc., as well as to actively promote the intelligent application of digital information technology in urban management, livelihood protection and administrative management.

Third, digital financial inclusion is an essential part of the digital economy. The development of the digital economy will be constrained by the level of digital financial inclusion, which requires the joint development of the digital economy and digital financial inclusion in concert. For regions with a relatively good development foundation, they should give full play to their digital advantages and economic advantages. Other recommendation includes the following: innovate digitally inclusive financial tools and explore and build a diversified and multi-level modern digital inclusive financial system to provide services for different groups of people. For regions with relatively weak development bases, preferential policies can be introduced. They should encourage local financial institutions to develop digitally inclusive financial services, guide the flow of financial and digital capital to the region and steadily improve the level of digital financial inclusion in the region.

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Conflict of interest

The authors declare no conflict of interest.

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