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Research on the Impact of Digital Economy on Urban Low-Carbon Development

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Abstract. Against the backdrop of accelerating digital transformation, the relationship between the development of the digital economy (DE) and urban low-carbon development (ULCD) has become an important issue in current research. Using 29 cities data covering from 2011 to 2022, this study constructs an ULCD index through the entropy-weighting method and employs a fixed-effects model to examine whether the DE contributes expansion to ULCD. Research has found that: (1) The DE can significantly promote UULCD. The coefficient of DE in the benchmark regression is 0.0000796. (2) After tail reduction and one period lag test, the DE coefficients were 0.0000973 and 0.0001041, respectively, and the research conclusion remained stable. (3) After heterogeneity testing, it can be found that the strength of the role of the DE in ULCD varies with the regional economic development status, and the promotion effect is more pronounced in low economic development areas, with a regression coefficient of 0.0002727.

Keywords: DE, ULCD, Entropy weight method

1. Introduction

The DE has gradually integrated into various aspects of economic operation and become an important force in promoting industrial transformation. By 2025, Chinese DE continue to expand, with an economic scale of 53.9 trillion yuan. From its proportion in the gross domestic product, the contribution of the DE is 42.8%, further highlighting its position in the national economy.The DE has become an important component of economic development. Digital infrastructure, human capital, and the institutional environment are important factors affecting the development of the DE. Improvements in digital conditions can further enhance its social effects [1]. However, access to and use of digital technologies vary across regions and population groups. In some areas, the relatively weak digital infrastructure limits the practical application and effectiveness of digital technologies [2]. Based on this, this article selects cities as research objects, constructs an evaluation index system for ULCD level, analyzes the impact of DE on ULCD.

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2. Research hypothesis

2.1. The impact of DE on ULCD

The DE has changed the traditional way of allocating production factors, improving economic efficiency through the flow of data resources, and intelligent production models. The DE can promote the transformation of economic growth models and also facilitate the transition of urban development from traditional high consumption models to green and low-carbon models. Previous studies have also shown that the DE can enhance the level of ULCD through technological innovation, industrial structure optimization, and other means [3].So:

H1: The DE development can significantly enhance the level of ULCD.

2.2. The impact of DE on ULCD under differences in economic development levels

Economic development varies across regions, and the conditions supporting industrial development differ accordingly. Traditional industries have a higher proportion in low economic development areas, and there is greater room for improving resource utilization efficiency [4]. Propose research hypotheses:

H2: The promotion effect of the DE on ULCD has heterogeneity in economic development levels, and the promotion effect is more pronounced in low economic development areas.

3. Variable design

3.1. Dependent variable

ULCD level (lcd). This article takes the level of ULCD as the dependent variable, including green resources, chemical oxygen demand emission intensity per GDP, sulfur dioxide emission intensity per GDP, and green invention achievements. Index is used to construct the lcd index, in Table 1.

Table 1. Explained variables

Dimension	Indicator	Symbol	Attribute
Green resource utilization	Green resources	Green	Positive
Pollution emission level	chemical oxygen demand emission intensity per GDP	COD	Negative
Pollution emission level	sulfur dioxide emission intensity per GDP	SO2	Negative
Green innovation capability	Green invention achievements	GPatent	Positive

3.2. Core explanatory variables

DE level (de). In this study, DE is used to describe the degree of digital development in citie as a key factor in the subsequent empirical analysis. The core explanatory variables are shown in Table 2.

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Table 2. Core explanatory variables

Dimension	Indicator	Symbol	Attribute
Digital infrastructure	Per capita number of broadband access ports	Internet	Positive
Digital technology development	Digital productivity	DP	Positive

3.3. Control variables

Combined with the influencing factors of lcd, the following are selected as control variables. Economic development level selects per capita GDP, technological innovation capability selects technological productivity, intelligent manufacturing level selects robot installation density, new quality productivity level selects regional new quality productivity level. This article presents a summary of variables, with specific indicators shown in Table 3.

Table 3. Variables summary

Variable	Variable	Symbol	Measurement Method
Dependent variable	LCD level	lcd	Entropy method
Core explanatory variable	DE development level	de	DE index
Control variable	Economic development level	pgdp	Per capita GDP
	Technological innovation capacity	tech	Technological productivity
	Intelligent manufacturing level	robot	Robot installation density
	New quality productive forces	npp	Regional new quality productive forces index
	Innovation input level	npi	New product economic investment

4. Model setting

4.1. Benchmark model

To examine the impact of the DE on ULCD, the following model is constructed:

$$LCD_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_2 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Among them, LCD_{it} represents the level of ULCD, DE_{it} represents the level of DE, $Control_{it}$ represents the set of control variables, μ_i represents the city fixed effect, and λ_t represents the time fixed effect [5].

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4.2. Calculation steps of entropy method

Assuming the original indicators: $X = (x_1, x_2, \ldots, x_m)$

Step 1: Standardization of indicators.

Positive indicators: $Z_{ij} = \frac{x_{iij} - min(x_j)}{max(x_j) - min(x_j)}$, Negative indicator: $Z_{ij} = \frac{max(x_j) - x_{iij}}{max(x_j) - min(x_j)}$

Step 2: Calculate the indicators weight. $LCD = \sum W_j Z_{ij}$. Obtain the annual lcd index for each city.

5. Empirical results

5.1. Descriptive statistics

Table 4 presents the descriptive statistical results of each variable. Overall, all variables have certain differences, which can meet the needs of subsequent regression analysis.

Table 4. Descriptive statistical results

Variable	Obs	Mean	Std. Dev.	Min	Max
lcd	342	0.0017115	0.0003013	0.0009837	0.002423
de	344	0.5096433	0.240781	0.118306	1.040783
pgdp	344	6.186485	3.013197	2.1978	17.363
tech	344	0.0219419	0.026913	0.000915	0.126264
robot	344	13940.17	22533.44	121.7104	143562.1
npp	344	0.0203024	0.0224222	0.001659	0.101732
npi	344	0.0123025	0.0074114	0.002845	0.035896

5.2. Correlation analysis

This article conducted correlation analysis and statistics, as shown in Table 5.

Table 5. Correlation analysis statistics

	lcd	de	pgdp	tech	robot	npp	npi
lcd	1.0000						
de	0.2893***	1.0000					
pgdp	0.0891*	0.6848***	1.0000				
tech	-0.0379***	0.0848***	0.3260***	1.0000			
robot	0.1932***	0.4082***	0.4381***	0.5716***	1.0000		
npp	0.1154**	0.2364***	0.5072***	0.9590***	0.6404***	1.0000	
npi	0.1850***	0.3749***	0.6028***	0.7594***	0.7112***	0.7996***	1.0000

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5.3. Multicollinearity test (VIF)

This article conducted VIF analysis, as shown in Table 6.

Table 6. VIF analysis

Variable	VIF	1/VIF
npp	28.94	0.034552
tech	25.92	0.038581
npi	4.5	0.222379
pgdp	4.04	0.24778
robot	2.42	0.412823
de	2.18	0.459045
Mean VIF	11.33	

The results show that there is no serious multicollinearity issue overall, which will not affect the results.

5.4. Benchmark regression analysis

Table 7 presents the article conducted benchmark regression analysis.

Table 7. Benchmark regression analysis

	(1) lcd	(2) lcd	(3) lcd	(4) lcd	(5) lcd
de	0.0000939**	0.0000844**	0.0000851**	0.0000686**	0.0000796**
	(0.0001003)	(0.0001058)	(0.0001080)	(0.0001075)	(0.0001133)
pgdp	-0.0000110**	-0.0000144*	-0.0000144*	-0.0000212**	-0.0000204*
	(0.00000836)	(0.00000818)	(0.00000795)	(0.00000975)	(0.0000102)
tech		-0.0018512**	-0.0018277**	-0.0040967**	-0.0048655**
		(0.0007619)	(0.0007823)	(0.0016464)	(0.0018732)
robot			0.0000000000264**	-0.0000000000239**	-0.0000000006577**
			(0.0000000002280)	(0.0000000000250)	(0.0000000004553)
npp				0.0041094*	0.0043323**
				(0.0023662)	(0.0026477)

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Table 7. (continued)

npi					0.0047768**
					(0.0053045)
Constant	0.0014955***	0.0015478***	0.0015475***	0.0015639***	0.0015216***
	(0.0000422)	(0.0000430)	(0.0000447)	(0.0000456)	(0.0000736)
Year fixed effect	control	control	control	control	control
Urban fixed effects	control	control	control	control	control
Observations	342	342	342	342	342
Number of city	29	29	29	29	29
R-squared	0.8209	0.8247	0.8247	0.8278	0.8300

After further considering other control factors in model (5), further indicating can effectively improve the ULCD level. Therefore, the benchmark regression results support hypothesis H1 proposed in this article.

5.5. Robustness test

This paper conducted robustness tests from two aspects: outlier handling and lag effects, in Table 8.

Table 8. Robustness test

	(1) Tail reduction treatment	(2) lags behind by one period
de	0.0000973***	
	(0.0001199)	
lde		0.0001041***
		(0.0000982)
pgdp	-0.0000199*	-0.0000218**
	(0.0000102)	(0.0000105)
tech	-0.0055969***	-0.0047963**
	(0.0019931)	(0.0020570)
robot	-8.86e-10***	-4.23e-10***
	(5.67e-10)	(5.10e-10)
npp	0.0046829*	0.0046041***

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Table 8. (continued)

	(0.0025735)	(0.0027366)
npi	0.0058627***	0.0022739***
	(0.0052862)	(0.0045531)
Constant	0.0015166***	0.0016135***
	(0.0000694)	(0.0000644)
Year fixed effect	control	control
Urban fixed effects	control	control
Observations	342	313
Number of city	29	29
R-squared	0.8358	0.8107

According to model (1), after tail reduction,the de remains positive is the regression coefficient, consistent with the benchmark regression results direction, indicating that extreme samples will not have a significant impact. The model (2) shows that the lagged variable coefficient (lde) is still positive, indicating the promotion effect of DE on ULCD. The above results further validate the reliability of H1.

5.6. Heterogeneity analysis

This article conducts heterogeneity analysis from two aspects: high economic regions and low economic regions, as in Table 9.

Table 9. Heterogeneity analysis

	(1) High economic areas	(2) Low economic areas
de	-0.0000874*	0.0002727*
	(0.0000984)	(0.0001385)
pgdp	-0.00000657**	-0.0000222
	(0.00000854)	(0.0000320)
tech	-0.0010209***	-0.0108967***
	(0.0020610)	(0.0032324)
robot	7.36e-10***	-5.71e-09***
	(6.41e-10)	(1.78e-09)
npp	-0.0020854**	0.0098335***
	(0.0028033)	(0.0019466)

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Table 9. (continued)

npi	-0.0002970**	0.0161008**
	(0.0077868)	(0.0067339)
Constant	0.0015741***	0.0014276***
	(0.0001428)	(0.0001160)
Year fixed effect	control	control
Urban fixed effects	control	control
Observations	135	207
Number of city	22	25
R-squared	0.8944	0.8371

Table 9 further analyzes the differences of DE on ULCD in different regions. The results showed that in high economic development areas, the DE impact coefficient was negative.

6. Conclusion

This article selects 29 cities from 2011 to 2022, and uses a two-way fixed effects model to test. The conclusions are as follows:(1) The DE can promote ULCD, and hypothesis H1 has been verified. The DE estimated coefficient is 0.0000796, which is significant. The tail reduction treatment and lagged one period test found that the impact direction of the DE did not change, indicating that the DE helps to improve the ULCD level of cities and has a certain degree of reliability.(2) The DE on ULCD impact varies by region, and hypothesis H2 is verified. The heterogeneity test results indicate that the regression coefficient of the DE in low economic areas is 0.0002727, which is significant, indicating that areas with lower levels of economic development have greater room for transformation.

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