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The Emission Reduction Role of Digital Economy - A New Perspective Based on Public Carbon Emission Concerns and New Urbanization

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Abstract: *No existing literature examines the impact of the digital economy on per capita carbon emissions in cities and industries from the perspectives of public carbon concern and new urbanization. Addressing this gap, this study empirically establishes that the digital economy reduces urban per capita carbon emissions, utilizing Chinese city-level data (2011-2021). This conclusion is subjected to rigorous testing. Heterogeneity analysis indicates that the impact of the digital economy on per capita carbon emissions varies by sector and region. Mechanistic insights highlight the digital economy's role in lowering emissions by enhancing public concern about carbon emissions and fostering new urbanization.*

Keywords: *Digital Economy; Public Concern about Carbon Emissions; New Urbanization; Per Capita Carbon Emissions*

1. Introduction

The substantial surge in carbon emissions significantly contributes to global warming. Urgent action is imperative to counter greenhouse gases like carbon dioxide emissions. The interplay between the digital economy and carbon emissions has garnered substantial scholarly interest. Presently, this field has yielded significant findings, yielding three primary conclusions. Firstly, the digital economy can diminish total [1-4] and intensity carbon emissions [5-7], while bolstering emission efficiency [8, 9]. Secondly, the digital economy can elevate carbon emissions due to increased energy demand [10], amplified carbon-intensive intermediate inputs in non-ICT sectors [11], and heightened regional energy consumption [12]. Moreover, some contend that digital economy growth may indirectly elevate emissions through reduced energy efficiency [13]. Lastly, a subset of studies suggests a non-linear relationship [6, 14].

While progress has been made in this field, three key aspects warrant deeper exploration: (1) When exploring the heterogeneity of the digital economy on carbon emissions, an analysis of industry heterogeneity is missing. (2) Existing research mainly examines the impact of formal environmental regulatory instruments on carbon emissions, such as carbon emissions trading [15], carbon tax [16, 17], environmental protection law [18], and environmental regulations [19]. But very few scholars have explored the role of public concern about carbon emissions in its. (3) While prior studies explore digital economy-carbon emission links via economic growth, financial development, industrial upgrades, and so on, there's limited focus on new urbanization's role.

Considering this, we empirically examine the influence, heterogeneity and mediation of the digital economy on per capita carbon emissions. We analyze relevant city-level data from China (2011-2021). Our findings highlight the digital economy's capacity to curtail urban per capita carbon emissions. The emission-reduction impact varies based on industry, region, and urban classification. We find that the digital economy reduces per capita carbon emissions by raising public concern about carbon emissions and promoting new urbanization.

This study enriches the current literature. Our approach offers a distinctive angle, probing the impact of the digital economy on per capita carbon emissions via public concern about carbon emissions and new urbanization—areas seldom explored. Moreover, this research introduces novel insights for policymakers, aiding in carbon emission governance, as well as advancing the goals of carbon peaking and carbon neutrality.

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2. Theoretical hypothesis

Digital infrastructure lays a strong base for public info access. The Internet platform lowers info search costs and gives public access [20]. This support for info sharing by the digital economy causes physical events to spark changes in public opinion online, forming a flow of online event dissemination. Sensitive info spreads rapidly online, following Metcalfe's law and the speed, global reach, and interaction of online info, resulting in the butterfly effect. To conclude, in the digital economy, the public learns quickly, thoroughly, conveniently, and accurately about various subjects beyond time and space constraints. Thus, this paper asserts the digital economy boosts public attention to carbon emissions. This paper asserts that public concern for carbon emissions curbs urban per capita carbon emissions through two routes: deterrence and incentive. For instance, higher public complaints prompt local governments to raise emission license fees [21]. This pressure subjects firms to legal penalties, fines, and greater compensation costs [22]. Companies boycotted by the public face reputational loss as socially conscious customers shift to other brands [23, 24]. Post-accidents, investors divest from affected firms, lowering their market value [25]. Meanwhile, worries about pollution yield notable environmental stock returns, encouraging firms to engage in environmental initiatives. Thus, public carbon concern fosters a preference for low-carbon products, industries, and firms, motivating low-carbon production.

Urbanization is a historical process where non-agricultural industries cluster in cities, while the agricultural population concentrates there—a hallmark of modernization for nations. China introduced the National New Urbanization Plan (2014-2020), the National New Urbanization Plan (2021-2035), and the 14th Five-Year New Urbanization Implementation Plan. Drawing from these documents and the essence, role, and economic principles of new urbanization, this paper asserts that the digital economy helps to promote the citizenship of the agricultural transfer population for the following reasons. The digital economy enhances the city's innovation capacity and creates a good environment for employment and entrepreneurship [26]. It notably helps migrant workers find jobs, create new employment opportunities, and enhance job quality, leading to higher income for both migrants and farmers. This income increase also benefits the integration of rural-to-urban migrants into city life. Second, the digital economy bridges the urban-rural gap. Additionally, it fosters modern agriculture [27]. Public efforts like expanding rural broadband and digital education narrow the rural-urban digital divide, crucially supporting rural enterprises, areas, and the nation's economic progress [28]. Aligned with the National New Urbanization Plan (2014-2020), this study maintains that implementing new urbanization has led to lower per capita carbon emissions using the following strategies. Firstly, new urbanization prioritizes innovation, scientific advancement, and optimized industries, which collectively decrease carbon emissions [29, 30]. Secondly, the central aspect of new urbanization involves efficient movement and allocation of production factors like labor, capital, and land, leading to reduced carbon emissions. Thirdly, new urbanization inherently drives intercity environmental collaboration, enhancing joint prevention, control, and management. These cooperative efforts enhance carbon emissions governance despite property rights challenges. Building on this, the paper puts forward several propositions.

H1: The digital economy cuts per capita carbon emissions.

H2: The digital economy diminishes per capita carbon emissions by intensifying public focus on carbon emissions and advancing new urbanization, thereby reducing such emissions.

3. Research Design

3.1 Model Setting

3.1.1 Benchmark model setting

The benchmark regression model for this paper is constructed as follows:

$$lnpem_{it} = \alpha_0 + \alpha_1 dec_{it} + \sum \alpha X_{it} + u_i + v_t + \mu_{it} \tag{1}$$

Where: i and t represent city and year, respectively; pem_{it} represents the city's per capita carbon emissions; dec_{it} represents the city's level of digital economic development; X represents a series of control variables. The u, v, and μ represent individual effects, time effects, and random errors, respectively.

3.1.2 Mediation mechanism test

To explore the intermediary mechanism of the digital economy and carbon emissions, this paper sets

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the following mechanism testing model based on the benchmark regression model:

$$R_{it} = \gamma_0 + \gamma_1 dec_{it} + \sum \gamma X_{it} + u_i + v_t + \mu_{it} \quad (2)$$

$$lnpem_{it} = \delta_0 + \delta_1 dec_{it} + \delta_2 R_{it} + \sum \delta X_{it} + u_i + v_t + \mu_{it} \quad (3)$$

In the above equation, R represents the mediating variables, which denote carbon emission concern and new urbanization, respectively. Other variable settings are consistent with equation (1). $\gamma_1 \times \delta_2$ represents the mediating effect, i.e., the impact of the digital economy on per capita carbon emissions through the mediating variable.

3.2 Variables and data

3.2.1 Explained variable: per capita carbon emissions

The EDGAR carbon emission gridded data is employed as follows: 1) The global annual carbon emission gridded data from 2011-2021 is selected, and ArcGIS 10.7 software is employed to correlate and consolidate global carbon emission data with Chinese cities. This process yields the total carbon emission data for 281 Chinese cities spanning 2011-2021. 2) The total carbon emission data is divided by the average annual population of each city to calculate the per capita carbon emission. Subsequently, the logarithm of this value is taken to generate the explanatory variables used in this study.

3.2.2 Explanatory variables: digital economy

This paper measures the level of the urban digital economy (*dec*) using the principal component method from five aspects, namely, the percentage of Internet users, the percentage of cell phone users, the percentage of people employed in the information transmission and technology service industry, the total amount of telecommunication services per capita, and the city's digital financial inclusion index.

3.2.3 Mechanism variables

Public carbon emission concern. The study gathered a total of 1.12 million carbon emission search data entries from 281 cities, covering the period from January 1, 2011, to December 31, 2021, via the Baidu Index's official website. Since Baidu Index provides absolute search volume (count), yearly sums were computed to derive the annual public carbon emission concern for each city.

Table 1 Construction of new urbanization indicators

Variable	Primary Indicators	Secondary Indicators	Indicator Attributes	Data Source
New Urbanization	Urbanization	Urbanization rate of total population (%)	Positive	Statistical yearbooks and annual reports of Chinese cities and provinces
	Basic public services	Number of urban workers covered by basic pension insurance (persons)	Positive	Urban and rural statistical yearbook
		Number of participants in basic urban medical insurance (persons)	Positive	Urban and rural statistical yearbook
	Infrastructure	Water penetration rate (%)	Positive	Urban and rural statistical yearbook
		Sewage treatment rate (%)	Positive	Urban and rural statistical yearbook
		Harmless treatment rate of domestic garbage (%)	Positive	Urban and rural statistical yearbook
		International Internet (households)	Positive	China Urban Statistical Yearbook
		Land area for public administration and public service facilities (km²)	Positive	Urban and rural statistical yearbook
	Resource environment	Urban built-up land area (km²)	Positive	Urban and rural statistical yearbook
		Energy structure (%)	Negative	China Industrial Economy Official Website
		Green coverage of built-up area (%)	Positive	Urban and rural statistical yearbook
		Annual average air quality	Negative	China Air Quality Online Detection and Analysis Platform

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New Urbanization. Based on the National New Urbanization Plan (2014-2020), this study indicators four primary indicators and 12 secondary indicators, and employs the entropy method to create the new urbanization index for Chinese cities. Table 1 demonstrates the new urbanization indicator system developed in this study.

3.2.4 Control variables

Drawing from the IPAT and STIRPAT models, this study considers the following control variables: 1) Population Density ($density$): Calculated as the number of individuals per square kilometer. 2) Real Economic Development Level ($lnrgdp$): Using the economic development level adjusted by the provincial GDP price index, with 2011 as the base period. 3) Technology Level ($tech$): Determined by the ratio of science expenditure to local financial expenditure in the general budget. Additional control variables include 4) Energy Structure (es): Represented by the ratio of coal consumption to energy consumption within the province. 5) Government Intervention (gov): Assessed through the proportion of local financial expenditure in the general budget to GDP. 6) Human Capital ($human$): Measured by the proportion of education expenditure to GDP, reflecting the human capital level in cities. 7) Financial Development (fa): Indicated by the ratio of financial institution loan balances at year-end to the city's GDP for the same year. 8) Industrial Structure (isa): Quantified by the tertiary industry's gross domestic product relative to the city's GDP.

3.2.5 Data sources

The data sources are the EDGAR, China Urban Statistical Yearbook, CNRDS, the Baidu Index official website, China Urban and Rural Statistical Yearbook, Provincial Statistical Yearbooks and Annual Reports, China Air Quality Online Detection and Analysis Platform, and EPS. Table 2 shows the descriptive statistics of all variables.

Table 2 Descriptive Analysis

Variable	Observed	Mean	Standard deviation	Minimum	Maximum
lnpem	3,091	11.0839	0.7608	9.1799	14.1069
dec	3,091	0.2237	0.7493	0.0001	10.9357
resilience	3,091	4.2751	3.4191	-2.3931	15.2377
Shichang	3,091	0.0871	0.0993	0.0100	0.8081
concern	3,091	2219.7080	5714.9290	0.0000	76523.0000
Chenz	3,091	0.1160	0.1013	0.0102	0.9259
density	3,091	0.3796	0.2538	0.0309	1.5055
tech	3,091	10.4665	1.4270	6.6241	15.5293
lnrgdp	3,091	20.9781	3.6714	14.1063	32.0191
Coal	3,091	0.9242	0.4433	0.0010	2.5369
gov	3,091	14.9403	0.7557	12.0308	18.2500
human	3,091	13.1769	0.7906	9.9059	16.2560
fa	3,091	16.5544	1.1741	13.7234	20.5984
isa1	3,091	0.4254	0.1010	0.1436	0.8387

4. Empirical results

4.1 Benchmark regression results

This study initially examines the causal relationship between the digital economy and total carbon emissions. The findings are displayed in Table 3. Columns (1) to (6) present the outcomes of the baseline regression with a gradual inclusion of control variables. In Column (6), the regression coefficient for the urban digital economy is -0.028, remaining significant at the 1% level. This outcome underscores the notable reduction in per capita carbon emissions due to the urban digital economy.

Table 3 Benchmark regression results

VARIABLES	(1) lnpem	(2) lnpem	(3) lnpem	(4) lnpem	(5) lnpem	(6) lnpem
dec	-0.039***	-0.035***	-0.033***	-0.027***	-0.027***	-0.028***
	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)
density		-0.012	-0.013	-0.013	-0.013	-0.013
		(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
tech		-0.019***	-0.011***	-0.005	-0.004	-0.004
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
lnrgdp		-0.012***	-0.011***	-0.009***	-0.008***	-0.008***
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
coal		0.015**	0.017**	0.005	0.005	0.005
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
gov			-0.089***	-0.017	-0.012	-0.013
			(0.014)	(0.017)	(0.017)	(0.017)
human				-0.133***	-0.129***	-0.129***
				(0.019)	(0.019)	(0.019)
fa					-0.027**	-0.027**
					(0.013)	(0.013)
isa1						-0.020
						(0.049)
Constant	11.093***	11.530***	12.739***	13.338***	13.641***	13.657***
	(0.002)	(0.038)	(0.200)	(0.226)	(0.269)	(0.270)
Observations	3,091	3,091	3,091	3,091	3,091	3,091
Adjusted R-squared	0.989	0.990	0.990	0.990	0.990	0.990
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The same applies to the following table.

4.2 Robustness test

4.2.1 Replacement of explanatory variables

Table 4 Robustness Tests

VARIABLES	(1) lnpercarbon	(2) lnpem	(3) lnpem	(4) lnpem	(5) lnpem	(6) dec	(7) lnpem
dec	-0.270***			-0.032***	-0.024***		-0.028***
	(0.033)			(0.009)	(0.009)		(0.007)
Internet		-0.004***					
		(0.001)					
index			-0.001*				
			(0.000)				
iv						0.233***	
						(0.017)	
Constant	2.809	13.469***	13.825***	13.659***	13.784***	-3.654***	14.148***
	(2.347)	(0.852)	(0.270)	(0.270)	(0.286)	(0.981)	(0.198)
Observations	3,079	1,120	3,091	3,047	2,585	3,091	3,091
Adjusted R-squared	0.766	0.996	0.990	0.990	0.990	0.873	0.990
Controls	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES	YES

In this study, we use carbon emission calculation methods and parameters from IPCC (2006), along with relevant parameters provided by the Chinese government. Total carbon emissions encompass urban electricity, steam and hot water heating, artificial gas, natural gas, and liquefied petroleum gas emissions. Next, the total carbon emissions derived above are divided by the average annual population size and logarithmic, which is the replacement variable for the explanatory variables of this paper, and then a robustness test is performed. The results in column (1) of Table 4 confirm that after replacing the explanatory variables, the coefficient of the digital economy is -0.270, which is significant at the 1% significance level. In summary, this paper concludes that the digital economy can reduce urban carbon emissions per capita, and this conclusion still holds after replacing the explanatory variables.

4.2.2 Substitution of explanatory variables

This study employs the "Internet+" index as a surrogate variable for the digital economy in robustness testing. Given that the "Internet+" index spans 2015 to 2018, the robustness test utilizes data from this

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period. Columns (2) in Table 4 illustrates that the coefficient for the "Internet+" index $Internet$) is -0.004, with significance at the 1% level. In conclusion, the "Internet+" index ($Internet$) and urban per capita carbon emissions exhibit a negative correlation, implying that the digital economy curbs the rise of urban per capita carbon emissions.

This study employs the degree of urban digital financial development as a substitute gauge for urban digital economy in robustness testing. The outcomes presented in column (3) of Table 4 reveal that the coefficient for digital finance (INDEX) is -0.001, with significance at the 10% level. In summary, the digital economy curbs the rise of per capita carbon emissions in cities, affirming the validity of Hypothesis 1.

4.2.3 Removal of related policy impacts

Deleting the municipality sample. Column (4) of Table 4 confirm that the coefficient of the digital economy (dec) is -0.032 and significant, indicating that the digital economy still reduces urban per capita carbon emissions after removing the municipality sample. Excluding cities and provinces related to carbon emissions trading. This paper excludes the cities with the above pilot policies. The results in column (5) of Table 4 show that the coefficient of the digital economy is -0.024, and significant at a 1% significance level, indicating that the digital economy still has an inhibitory effect on urban per capita carbon emissions after excluding the related policies.

4.2.4 Endogeneity problem treatment

To address endogeneity, this study constructs instrumental variables. Alipay and Balance Bao City symbolize China's digital finance, with Hangzhou at the forefront. Scholars often use digital finance as a proxy for China's digital economy. Hence, proximity to Hangzhou may imply better digital economy development. Importantly, the city's distance to Hangzhou is unrelated to per capita carbon emissions. Thus, the spherical distance between cities and Hangzhou serves as a suitable instrumental variable, meeting relevance and exclusivity criteria. Notably, the digital economy evolves, while the city-Hangzhou distance remains constant. Therefore, our chosen instrumental variable is the product of this distance and international Internet users ($iv1$). Table 4, column (6), presents two-stage least squares first-stage results, revealing a significant positive correlation between the local digital economy and instrumental variable 1 ($iv1$). Column (7) displays second-stage results, indicating a -0.028 coefficient for the digital economy (dec), significantly supported at the 1% level, reinforcing hypothesis 1.

4.3 Heterogeneity Analysis

Table 5 Analysis of the heterogeneity

VARIABLES	(1) lnpnong	(2) lnpdian	(3) lnpjian	(4) lnpjiao	(5) lnpem	(6) lnpem	(7) lnpem
dec	-0.161**	-0.084**	-0.037*	-0.096***	-0.026***	-0.003	-0.046**
	(0.069)	(0.039)	(0.022)	(0.028)	(0.009)	(0.006)	(0.021)
Constant	17.536***	15.455***	19.074***	12.192***	13.004***	13.661***	14.886***
	(2.459)	(1.404)	(1.435)	(1.140)	(0.498)	(0.422)	(0.633)
Observations	2,518	2,400	2,529	2,529	1,243	1,188	660
Adjusted R-squared	0.827	0.940	0.873	0.913	0.989	0.993	0.987
Controls	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES	YES

To explore how the digital economy impacts total carbon emissions across different industries, this study obtains carbon emissions data for agriculture, electric power, construction, and transportation industries from the official EDGAR website. The total carbon emissions of these industries divided by the number of people working in each industry is the per capita carbon emissions of the industry. Table 5, column (1)-(4), presents empirical findings regarding the influence of the digital economy on per capita carbon emissions within agriculture, electric power, construction, and transportation industries, respectively. The results indicate that the digital economy reduces per capita carbon emissions in all these industries. Specifically, the digital economy has the most significant impact on lowering per capita carbon emissions in agriculture, followed by transportation, electric power, and construction industries.

To determine whether the digital economy affects per capita carbon emissions differently across China's economic zones, this study divides China into three regions: East, central, and West, and examines the regional variations in the impact of the digital economy on per capita carbon emissions. Table 5, sections (5)-(7), present empirical results of how the digital economy influences per capita carbon emissions in the eastern, central, and western regions, respectively. The findings indicate that the

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digital economy reduces per capita carbon emissions in both eastern and western cities, while its emission-reducing effect is not significant in the central region.

4.4 Testing Intermediary Mechanisms

Firstly, we explore the role of public carbon concern in the relationship between the digital economy and per capita carbon emissions. In Table 6, column (1), regression results between the digital economy and public carbon emission concern indicate a positive and significant association, suggesting the digital economy promotes public concern. In column (2), when including carbon emission concern and per capita carbon emission, the carbon emission concern exhibits a negative and significant. This signifies that the digital economy curtails per capita carbon emissions by heightening public awareness of carbon emissions.

Table 6 The Mechanism Tests

VARIABLES	(1) Concern	(2) lnpem	(3) Chenz	(4) lnpem
dec	3.488***	-0.019***	0.028***	-0.025***
	(0.444)	(0.007)	(0.006)	(0.007)
Concern		-0.003***		
		(0.001)		
Chenz				-0.084**
				(0.040)
Constant	-35.880***	13.566***	-0.014	13.656***
	(9.417)	(0.269)	(0.118)	(0.269)
Observations	3,091	3,091	3,091	3,091
Adjusted R-squared	0.803	0.990	0.880	0.990
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

Secondly, the role of new urbanization is examined to understand the digital economy's impact on per capita carbon emissions. In Table 6, column (3), regression results between the digital economy and new urbanization demonstrate a positive and significant digital economy coefficient at the 1% significance level, implying digital economy promotion of new urbanization. In column (4), when considering new urbanization and per capita carbon emissions, the coefficient for new urbanization appears negative and significant at the 1% level. This aligns with the benchmark regression outcomes, confirming that the digital economy suppresses per capita carbon emissions by fostering new urbanization in cities.

5. Conclusions and discussion

Earlier studies examining the nexus between the digital economy and carbon emissions has yielded valuable insights. However, these studies have overlooked the roles of public carbon concern, new urbanization, and industry heterogeneity in this relationship. In our empirical analysis, we examine this connection, along with its variations, and underlying mechanisms, using China's city-level data from 2011-2021. Surprisingly, we find that the digital economy leads to a reduction in per capita carbon emissions. This contradicts earlier conclusions that associated the digital economy with increased per capita carbon emissions [2]. We attribute this effect to the digital economy's ability to enhance public awareness of carbon emissions and promote new urbanization. Our findings demonstrate that the digital economy significantly curbs per capita carbon emissions in agriculture, transportation, power industry, and construction. This emission reduction effect holds for eastern and western cities. Thus, China's approach to environmental management should be tailored to specific industries and regions. This study has roughly estimated the per capita carbon emissions of the four industries using the available data. In the future, we hope to estimate the carbon emissions by new methods, e.g., field surveys, new databases, etc.

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