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Impact of Economic Policy Uncertainty on Carbon Emissions: Evidence at China's City Level

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Estimating the impact of economic policy uncertainty (EPU) on carbon emissions is crucial for formulating emission reduction targets and policies. Using the unbalanced panel data of 325 prefecture-level cities in China from 2001 to 2017 and a two-way fixed-effects model, this paper investigates the impact of economic policy uncertainty on city's carbon emission intensity. We find that one percentage point increase in economic policy uncertainty will make the city's carbon emission intensity increase by 4.28 percentage points, and by 0.244 tons per ten thousand yuan at an absolute level. The findings imply that policy makers need to consider the potential threat of economic policy uncertainty on carbon peaking and carbon neutrality in China.

Keywords: carbon emissions, economic policy uncertainty, heterogeneous effects, green and low-carbon transformation, emission reduction

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HIGHLIGHTS

- The impact of economic policy uncertainty on city's carbon emissions is estimated.
- We use a dataset of 325 Chinese cities from 2001 to 2017.
- We find that economic policy uncertainty will increase carbon emission intensity.
- The above result is stronger for cities in the Eastern and Central regions.
- The above result is more significant for cities with more environmental investment and R&D investment.

1 INTRODUCTION

Estimating the impact of economic policy uncertainty on carbon emissions is crucial for formulating emission reduction targets and policies (Li et al., 2022; Xian et al., 2022). With the continuous improvement of the level of economic development and per capita income, the environmental pollution problems have increased (Chen et al., 2021). And more and more people pay attention to and attach importance to a green and low-carbon life. Currently, the economic growth model of high energy input, high energy consumption, and high emission have gradually been abandoned by countries around the world, and more and more countries and regions have begun to turn to a green and low-carbon development model. Farhad and Ehsan (2020) estimate the energy transition patterns in 45 Asian countries with different incomes. They find that economic growth has a positive relationship with the energy transition, while CO_2 emissions negatively influence energy transition. As the world's largest carbon emitter, the Chinese government has set a design route and timetable for carbon dioxide emission reduction targets, requiring that carbon peaks be reached by 2030 and carbon neutrality be achieved by 2060 (Xian et al., 2022; Zeng et al., 2022). International experience shows that it will take 50–60 years for developed countries in Europe and America to realize the transition from carbon peaking to carbon neutrality. Conversely, the Chinese government has announced to the world that China will achieve the transition within the next 30°years, which also indicates that China will be far more challenging to achieve carbon neutrality than developed countries in Europe and America (Liu et al., 2022). Moreover, China is still in the transition period of rapid urbanization and industrialization, which further exacerbates the difficulty of achieving carbon neutrality. To achieve carbon neutrality as scheduled, an important task for the Chinese government is to clarify the factors that affect urban carbon emissions and to reasonably evaluate the implementation effects of various emission reduction policies.

For a long time, the Ministry of Industry and Information Technology of China has focused on energy consumption standards and enterprise development, the National Development and Reform Commission in charge of carbon emissions and economic growth and the Ministry of Environmental Protection in charge of pollution emissions and ecological environment. The incompatibility between environmental goals and economic goals (Swain, 2018), as well as the interfering economic policies from “multiple departments” are important reasons for the low efficiency of China’s carbon emission management (Yang et al., 2016). Furthermore, the uncertainty of economic policies caused by the interference from “multiple departments” and inconsistent policy timing has greatly reduced the reduction effect of China’s carbon dioxide emissions, greatly weakened the expected results of emission reduction policies, and hindered the realization of the “3060 target” as scheduled (Cui et al., 2021). Aiming to accelerate the green and low-carbon transformation of Chinese cities, this paper mainly analyzes the impact of economic policy uncertainty on China’s urban emission reduction and adopts a two-way fixed effect model to examine the impact of economic policy uncertainty on urban carbon emissions in China. The paper intends to clarify the real impact of economic policy changes on China’s urban carbon emissions and put forward policy recommendations that can accelerate the green and low-carbon transformation of Chinese cities, which has instructive and practical significance for achieving carbon peaking before 2030.

Due to the lack of regional heterogeneity of the economic policy uncertainty index at the national or sectoral level, it cannot truly reveal the impact of economic policy uncertainty on city’s carbon emissions (Yu et al., 2021). The motivation of this paper is to use a regional economic policy uncertainty index in China to estimate its impact on the city’s carbon emissions, rather than a national or sectoral economic policy uncertainty index. The study finds that elevated economic policy uncertainty will hinder the green and low-carbon transformation of cities. If a city’s economic policy uncertainty increases by 1 percentage point, the city’s carbon emission intensity will increase by 0.244 tons per ten thousand yuan in absolute amount, and 4.28 percentage points in relative amount. This is especially evident in the central and eastern cities, cities dominated by the secondary industry, and cities with more investment in environmental pollution control and R&D.

Our study contributes to the literature in the following ways. First, this paper uses a regional economic policy uncertainty index rather than a national or sectoral-level economic policy uncertainty index. The regional economic policy uncertainty index has sufficient regional heterogeneity, which can more accurately estimate the impact of economic policy uncertainty in different cities on carbon emissions. Second, the previous literature usually examines the impact of economic policy uncertainty on carbon emissions from the firm level (Yu et al., 2021), while this paper focuses on the city level and quantitatively measures the magnitude of the impact. Third, the paper examines the impact of economic policy uncertainty on urban carbon emissions from multiple dimensions, such as geographic region, industrial structure, environmental protection investment, and R&D investment, and puts forward targeted policy recommendations to accelerate urban green and low-carbon transformation.

The paper is organized as follows: **Section 2** presents the literature review. **Section 3** is the methodology, variables selection, and data sources. **Section 4** introduces the empirical results, heterogenous analysis, and robustness checks. The final section concludes this paper and provides some policy implications.

2 LITERATURE REVIEW

Historical data demonstrate that more than 70% of global carbon emissions come from cities, and less than 30% come from other regions (Cai et al., 2021). Hence, the urban carbon emission intensity directly determines the carbon emission level of a country or region. To speed up the green and low-carbon transformation of cities, the first condition is to make clear the main sources and influencing factors of urban carbon emissions.

Generally, there are two main sources of urban carbon emissions, one is the industrial sector and the other is the residential sector. The former is closely related to factors such as the stage of economic development, the level of economic development, industrial structure, the level of scientific and technological innovation, and the investment in environmental protection management (Xie et al., 2017; Liu et al., 2021a; Xian et al., 2022). The latter is highly correlated with urban population size, per capita income, residents’ low carbon awareness, and urban geographic distribution (Ribeiro et al., 2019; Cai et al., 2020; Yi et al., 2021). Generally speaking, the relationship between urban economic development and carbon emission intensity satisfies the environmental Kuznets curve (Jiang L et al., 2019). When a city’s economic development level is low, carbon emissions are also at a low level, but with the rapid economic development and the increase of per capita income, both the total amount and intensity of carbon emissions rise rapidly. When the urban economic development reaches a certain level, the continuous increase of per capita income will reduce the urban carbon emission intensity, and thus significantly improve the urban environmental quality. In this type of literature, many scholars also believe that in addition to the industrial sector and the residential sector, another important factor affecting the level of urban carbon emissions is the spatial spillover of carbon emissions between adjacent cities (Liu et al., 2020; Rong et al., 2020; Wang et al., 2020).

Among many influencing factors of urban carbon emissions, economic policy is a very important one. This is because the formulation of economic policies not only directly determines the development direction of a city in the short and medium to long terms and affects the level of the city's future economic development, but also the environmental and industrial policies derived from economic policies will indirectly change the total amount and intensity of urban carbon emissions. Therefore, attention needs to be paid to the systemic impact of economic policies on urban carbon emissions (Dietz and Venmans, 2019; Danish et al., 2020; Hu et al., 2020; Radmehr et al., 2021).

In recent years, the changing laws of economic policy around the world are increasingly indistinct and the frequency of changes is accelerating. Although the impact of deterministic economic policies on urban carbon emissions is predictable, if the changes in economic policies are unpredictable, it will bring huge risks and challenges to the city's green and low-carbon transformation. Currently, the focus of the literature is shifting from deterministic to uncertain economic policies, focusing on the impact of economic policy uncertainty on carbon emissions in countries around the world.

The first category of literature conducts research from the national level. For example, Adams et al. (2020) use panel data of 10 resource-rich countries in the world from 1996 to 2017 to study and find that economic policy uncertainty has a significant positive effect on carbon dioxide emissions in the long run. Adedoyin and Zakari (2020) study the United Kingdom data from 1985 to 2017 to conclude that economic policy uncertainty reduces the growth rate of carbon dioxide emissions in the short term, but increases carbon dioxide emissions in the long run. Khan et al. (2022) use historical data of four East Asian countries, China, Japan, South Korea, and Singapore, and conclude that economic policy uncertainty will accelerate carbon dioxide emissions. Based on panel data of the world's top ten carbon dioxide emitters from 1990 to 2015, Anser et al. (2021) find that when economic policy uncertainty increases by 1%, carbon dioxide emissions increase by 0.11% in the short term and 0.12% in the long term.

The second category of literature conducts research from provincial and industry levels. For example, Liu and Zhang (2022) use data from Chinese provinces to find that the impact of economic policy uncertainty on carbon emissions has regional differences. Based on the United States industry data, Jiang Y et al. (2019) find that economic policy uncertainty will increase carbon dioxide emissions and their growth rates by destabilizing industry production. Wei et al. (2022) point out that the unpredictability of changes in economic and environmental policies will inhibit the rapid development of the photovoltaic power generation industry and the electrolysis hydrogen production industry, thereby hindering the green and low-carbon transformation. Dou et al. (2022) examine the impact of economic policy uncertainty on carbon markets. The results demonstrate that economic policy uncertainty has a long-term negative impact on carbon futures price returns. That is to say, economic policy uncertainty will reduce the enthusiasm of the industries included in carbon trading to participate in carbon trading, which is not conducive to reducing carbon dioxide emissions (Bilgili et al., 2022a) use the SVAR model to investigate the impacts of income, country-level world uncertainty, country-level economic policy uncertainty, and energy price index on electricity retail sales in United States. They find that United States country-level world uncertainty index and United States economic policy index have negative impacts on electricity end-use.

In addition, there are a few pieces of literature that carries out research from the enterprise level. For example, Yu et al. (2021) examine the impact of economic policy uncertainty on enterprise carbon emissions, which is the first at the enterprise level. They find that to avoid the negative impact of economic policy uncertainty, enterprises tend to use high-carbon traditional fossil energy, which would lead to a substantial increase in the carbon emission intensity of enterprises.

To sum up, this paper finds through the literature review that economic policy is an important factor affecting the economic development, energy consumption and carbon emissions of a country or region. Changes in economic policies will not only change people's expectations for future economic development and industrial restructuring, but also indirectly affect energy efficiency and the green and low-carbon transition. In the existing literature, studies on the impact of economic policy changes on carbon emissions mainly focus on the national, sectoral and firm levels, and most of them use the economic policy uncertainty index at the national and sectoral levels. Due to the lack of volatility and regional heterogeneity of the economic policy uncertainty index at the national and the sectoral level, it cannot truly reveal the impact of economic policy uncertainty on city's carbon emissions, which is also the most obvious deficiency of the existing literature. This paper uses a regional economic policy uncertainty index in China to study its impact on city's carbon emissions, which can effectively make up the deficiency of existing research literature. The regional economic policy uncertainty index in China can reflect the economic policy differences and uncertainty levels in different regions of China, which helps to reveal the different responses of different cities' carbon emissions to economic policies. Currently, China is the largest carbon emitter in the world, with more than 70% of carbon emissions coming from cities. How to accurately and scientifically assess the impact of economic policy uncertainty on city's carbon emissions is directly related to China's current and future green and low-carbon transition. In addition, the empirical results of this paper could also provide significant decision-making basis for the Chinese government to achieve the dual carbon goals.

3 METHODOLOGY AND DATA SOURCES

3.1 Methodology

This paper adopts a two-way fixed-effects model, which is a popular approach in the economic literature (Yu et al., 2021; Chen and Zhu, 2022; Xie et al., 2022), to study the impact of economic policy uncertainty on urban carbon emissions. And the specific regression model is set as follows:

$$carbon\_inten_{it} = a_0 + a_1 \cdot \log\_EPU_{it-1} + \sum_{j=1}^{n} \beta_j \cdot controls_{ijt} + city_i + year_t + \varepsilon_{it} \tag{1}$$

here, i and t represent the city and year, respectively; $carbon\_inten$ represents the carbon emission intensity of the city, log_EPU represents the logarithm of the urban economic policy uncertainty, and $controls$ represents the city-level control variable set, including the urban real GDP per capita, the total urban population at the end of the year, the proportion of employees in the primary industry, the proportion of employees in the secondary industry, the number of industrial enterprises above designated size and the actual foreign direct investment. $city_t$ is the city fixed effect, $year_t$ is the year fixed effect, and ε_{it} is the unobservable error term.

3.2 Data Sources and Variables Selection

Unbalanced panel data of 325 prefecture-level cities in China from 2001 to 2017 are obtained from China Urban Statistical Yearbook.[1] In the baseline regression, we take the full sample data for regression analysis and use the balanced panel data composed of 312 consecutive prefecture-level cities as a robustness test.

The explained variable in this paper is urban carbon emission intensity. Firstly, we obtain ten energy consumptions of each city from the China Urban Statistical Yearbook, which are raw coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas, natural gas, and electricity. Secondly, the total urban carbon emissions can be obtained by multiplying various energy consumptions by their respective carbon dioxide emission conversion coefficients. Among them, the carbon emission conversion coefficients of raw coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas, natural gas, and electricity are 1.9003, 2.8604, 3.0202, 3.1705, 2.9251, 3.0179, 3.0959, 3.0103, 2.1622, and 1.0134, respectively. Then, the city's nominal GDP is converted to real GDP using the GDP deflator (which was 100 in the year 2000) of the province where the city is located. Finally, the total urban carbon emissions are divided by the actual GDP of the city to obtain the urban carbon emission intensity, the unit is tons per ten thousand yuan.

The explanatory variable is the uncertainty of urban economic policy. As the existing literature mainly adopts the method of Baker et al. (2016) to construct the economic policy uncertainty index of various countries in the world, so far there is no literature to construct the economic policy uncertainty index at the Chinese city level. In this case, this paper mainly adopts the economic policy uncertainty index at the provincial level in China from 2000 to 2017 constructed by Yu et al. (2021), [2] and takes the economic policy uncertainty index of the province where the city is located as the economic policy uncertainty index of the city.

According to the research settings of existing literature, we mainly control factors such as urban economic development level, urban population size, urban industrial structure, number of industrial enterprises, and foreign direct investment in the regression (Huang et al., 2020; Chen and Ma, 2021). China's urban economic development is positively correlated with energy consumption and carbon emissions (Chen and Zhu, 2022). In this paper, the urban economic development level is expressed by the city's real GDP per capita. We convert nominal GDP per capita into real values using the GDP deflator (which was 100 in the year 2000) for the province where the city is located and take the logarithm. Fragkias et al. (2013) point out that carbon emissions scale proportionally with urban population size in the United States. Urban areas consume more than 66% of the world's energy and generate more than 70% of global greenhouse gas emissions. Therefore, it is necessary to control the urban population size in the regression. The urban population size is expressed as the logarithm of the total population at the end of the year. Dong et al. (2020) and Chen and Zhu (2022) argue that industrial structure and scale of manufacturing enterprises are important factors affecting regional energy consumption and carbon emissions. Therefore, this paper introduces the urban industrial structure and the number of manufacturing enterprises in the baseline regression. The urban industrial structure is represented by the proportions of employees in the primary industry and the secondary industry. The number of manufacturing enterprises is represented by the logarithm of the number of industrial enterprises above designated size in cities. China is one of the largest emitters of global greenhouse gas emissions and the impact of foreign direct investment (FDI) on China's carbon emissions is crucial (Liu et al., 2021b) find that FDI positively affects China's carbon emissions. Foreign direct investment is expressed as the logarithm of the actual foreign direct investment in the whole city. We use the fixed asset investment price index (which was 100 in the year 2000) of the province where the city is located to convert the nominal investment into real value. It should be noted that the GDP deflator and fixed asset investment price index of each province in China are taken from the National Bureau of Statistics of China.

In further discussion, we introduce a total of four groups of heterogeneity discussions. First, the whole sample is divided into the eastern region, central region, western region, and northeastern region. Second, according to the median investment of urban environmental pollution control, the whole sample is divided into high and low groups. Third, according to the median proportion of urban secondary

[1]The minimum value of the number of cities in the 2001–2017 China Urban Statistical Yearbook is 314, and the maximum is 325. Therefore, we can obtain the unbalanced panel data of 325 prefecture-level cities.

[2]The provincial economic policy uncertainty index in China is constructed by Yu et al. (2021), and the time period is covering 2001–2017. Therefore, we use the same time period to do the empirical research.

TABLE 1 | Descriptive statistics.

Variables	Definition	Observations	Mean	S.D.	Min	Median	Max
carbon_inten	Urban carbon emissions intensity	3,691	5.6990	5.1473	1.0016	4.2552	46.568
laglog_epu	The logarithm of urban economic policy uncertainty in the previous year	5,046	4.4941	0.5371	1.4106	4.4943	5.7946
log_realGDP	The logarithm of urban real GDP per capita	3,833	15.313	1.0184	12.989	15.192	18.557
log_population	The logarithm of the total urban population at the end of the year	5,268	5.9984	0.9324	3.4203	5.9423	9.1230
share_agri	The proportion of employees in the primary industry	5,213	0.0344	0.0672	0.0002	0.0123	0.5013
share_indus	The proportion of employees in the secondary industry	5,240	0.4198	0.1533	0.0346	0.4234	0.8058
num_firm	The logarithm of the number of industrial enterprises above designated size	4,039	6.6243	1.2930	3.2189	6.4998	10.631
log_FDI	The logarithm of actual foreign direct investment	4,994	9.6343	2.0869	3.5835	9.6436	14.515
log_envirinput	The logarithm of the investment in environmental pollution control	1,796	9.9144	1.9625	2.8904	9.9363	15.374
log_tech	The logarithm of science and technology expenditure	2,432	10.954	1.1544	7.2377	10.738	15.181

TABLE 2 | The baseline results.

	(1)	(2)	(3)
Variables	carbon_inten	carbon_inten	carbon_inten
laglog_epu	**0.160****	**0.244*****	**0.244****
	(0.068)	(0.043)	(0.109)
log_realGDP		−12.752***	−12.752***
		(0.637)	(0.943)
log_population		0.072	0.072
		(0.145)	(0.185)
share_agri		−8.593***	−8.593***
		(2.377)	(2.442)
share_indus		−2.237**	−2.237*
		(0.886)	(1.290)
num_firm		0.841***	0.841***
		(0.209)	(0.262)
log_FDI		0.038	0.038
		(0.038)	(0.049)
constant	5.005***	194.609***	194.609***
	(0.298)	(9.725)	(14.710)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Clustering SE	NO	NO	YES
Observations	3,650	3,409	3,409
R-squared	0.711	0.883	0.883

*Notes: Standard errors are in parenthesis, *** denotes p < 0.01, ** denotes p < 0.05, * denotes p < 0.1. FE is the fixed effect. Clustering SE means that the standard errors are clustered at the provincial level when indicated.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

industry employment, the whole sample is divided into high and low groups. Fourth, the full sample is divided into high and low groups according to the median of urban science and technology expenditure.

Table 1 is the descriptive statistics of the relevant variables in this paper. It can be seen from **Table 1** that from 2001 to 2017, the average carbon emission intensity of 325 prefecture-level cities in China was 5.699 tons per ten thousand yuan, the minimum value was 1, and the maximum value was 46. This result shows that different cities in China experience huge changes in carbon emission intensity in different years. In reality, the Chinese government's increasing emphasis on environmental protection and the formulation of carbon peaking and carbon neutrality goals are all significant reasons for the continuous decline of carbon emission intensity in Chinese cities. Compared with the drastic changes in the carbon emission intensity of Chinese cities, the volatility of economic policy uncertainty in Chinese cities is relatively weak, with a standard deviation of only one-tenth of the former. On average, employees in the primary industry account for 3.4%, employees in the secondary industry about 42%, and employees in the tertiary industry account for 54.6%. The number of industrial enterprises above the designated size is 2,026, the actual foreign direct investment is 969.41 million United States dollars, the expenditure on science and technology is 4,119.31 million yuan, and the investment in environmental pollution control is 1,105.27 million yuan.

4 EMPIRICAL RESULTS AND ANALYSIS

4.1 Basic Results

Table 2 is the baseline regression results. Column (1) does not add any control variables, only the city fixed effect and the year fixed effect are controlled. The results demonstrate that the estimated coefficient of laglog_epu is 0.160 and is significantly positive, manifesting that the greater the uncertainty of urban economic policy, the higher the carbon emission intensity of the city. Columns (2) and (3) add multiple control variables such as urban economic development, urban economic scale, and industrial structure based on column (1), and the regression standard error of column (3) is clustering in the province level. The results show that the estimated coefficient of laglog_epu is 0.244 and is significantly positive, indicating that when the uncertainty of urban economic policy increases by 1 percentage point, the city's carbon emission intensity will increase by 0.244 tons per 10,000 yuan, which is an increase of 4.28 percentage points compared to the average carbon emission intensity of the city (0.244/5.699 = 0.0428). This result is consistent with Wang et al. (2022). Using the cross-country data for 137 countries from 1970 to 2018, they investigate the impact of economic policy uncertainty on CO_2 emissions and find that EPU would increase CO_2 emissions. However, Abbasi and Adedoyin (2021) argue that a national economic policy uncertainty index has a statistically insignificant effect on China's CO_2 emissions from 1970 to 2018.

The above baseline results raise an intriguing question as to why elevated urban economic policy uncertainty leads to higher urban carbon intensity. We believe there are two main reasons for this: First, economic development is closely related to energy consumption and carbon dioxide emissions. For a long time, China's economic development has been driven by energy consumption. If the economic policy lacks sufficient stability and continuity, it is bound to cause great harm to the urban low-carbon transformation. In this case, it will inevitably lead to an increase in the intensity of urban carbon emissions. This situation also exists in the world's major developed countries (Anser et al., 2021). Second, the production and energy consumption behaviors of enterprises are closely related to the stability of regional economic policies. For example, Yu et al. (2021) analyze the enterprise survey data in the Chinese tax survey data and conclude that if the economic policy stability of the province where the enterprise is located is worse and the degree of economic policy uncertainty is higher, the enterprise in the region is more inclined to use high-carbon-density fossil energy rather than low-carbon-density power resources during the normal production. Over time, this will lead to an increase in both the total carbon emissions and the carbon emissions intensity of enterprises in the region and ultimately lead to an increase in the urban carbon emissions intensity. Currently, a growing body of literature suggests that elevated economic policy uncertainty is detrimental to both urban low-carbon transformation and enterprise emissions reduction (Jiang L et al., 2019; Adams et al., 2020; Yu et al., 2021). To smoothly achieve China's "3060 target" as scheduled, it is necessary to be cautious about the substantial adjustment of economic policies and reduce the negative impact caused by changes in economic policies (Amin and Dogan, 2021).

The regression results of control variables are also in line with expectations. First, the estimated coefficient of log_realGDP is significantly negative, manifesting that the higher the level of economic development, the lower the urban carbon emission intensity. This is because the higher the level of economic development, the more willing the city is to pursue high-quality development, and the more capable it is to accelerate the green and low-carbon transformation. Wang et al. (2022) find that a higher level of economic development would reduce the environmental adverse effect of EPU. Second, the more industrial enterprises above the designated size, the higher the urban carbon emission intensity. Third, the regression coefficients of the proportion of employees in the primary industry and the secondary industry are both significantly negative, and the coefficient of the former is four times that of the latter. Fourth, urban population size has an insignificantly positive effect on carbon emissions. Ribeiro et al. (2019) argue that urbanization leads to increasing carbon emissions is controversial in the literature. They find that there is a coupled role between population and density on carbon emissions. In addition, foreign direct investment on urban carbon emission intensity is positive, but not significant. However, for Japan, South Korea, and Singapore, foreign direct investment can boost the quality of the environment and reduce carbon emissions covering the period of 1997–2020 (Khan et al., 2022).

4.2 Heterogenous Analysis

Many studies have shown that the mechanisms through which policy uncertainty affects carbon emissions include regional economic development, industrial structure, environmental protection emphasis, and green innovation (Cheng et al., 2019; Bilgili et al., 2021; Gu et al., 2021; Li et al., 2021; Wen and Zhang, 2022; Xie et al., 2022). Economic policy uncertainty is a relatively macroscopic factor, which can not only affect carbon emissions by changing the regional economic development and industrial structure, but also change carbon emissions by affecting the environmental protection emphasis and the green innovation. Therefore, the heterogeneity analysis in this paper focuses on these four dimensions to provide evidence for the transmission mechanisms of economic policy uncertainty affecting city's carbon emissions. The four dimensions are the city's geographic region (a proxy variable of regional economic development), industrial structure, investment in environmental protection, and R&D investment.

China has a vast territory, and the level of economic development presents the basic pattern of "strong east and weak west" and "strong south and weak north." Therefore, the whole sample is divided into four sub-samples: eastern region, central region, western region, and northeastern region, and based on this, the impact of economic policy uncertainty in different regions on urban carbon emissions is investigated. The regression results are shown in **Table 3**. Columns (1) to (4) of **Table 3** represent the estimation results for the eastern, central, western, and northeastern regions in turn. We find that the estimated coefficients of laglog_epu are significantly positive in both the eastern and central regions, which is consistent with the baseline regression results in **Table 2**. In the eastern and central regions of China, the worse the economic policy stability and the higher the uncertainty, the higher the urban carbon emission intensity. In the western region, although the estimated coefficient of laglog_epu is positive, it is not significant, indicating that changes in urban economic policy uncertainty cannot significantly change urban carbon emission intensity. In the northeastern region, the estimated coefficient of laglog_epu is negative and insignificant. Overall, compared with the western and northeastern regions, the higher the level of economic development in the eastern and central regions, the more significant the impact of economic policy uncertainty on the intensity of urban carbon emissions. It can be inferred that the level of regional economic development is an important factor affecting the response of urban carbon emissions to economic policy uncertainty.

Table 4 demonstrates the differentiated performance of urban carbon emission intensity in the face of economic policy uncertainty and fluctuations between cities with high and low investment in environmental pollution control. Column (1) of **Table 4** corresponds to cities with high investment in environmental pollution control, and column (2) corresponds to cities with low investment in environmental pollution control. The results show that the estimated coefficient of laglog_epu is significantly positive in column (1), which is consistent with the baseline regression results. However, in column (2), the estimated coefficient of laglog_epu is not significant, manifesting that in cities with low investment in environmental pollution control, the urban carbon emission intensity is not significantly affected by economic policy uncertainty. It can be seen that when a city

TABLE 3 | Results for the baseline regression with regional differences.

	(1) Eastern region	(2) Central region	(3) Western region	(4) Northeastern region
Variables	**carbon_inten**	**carbon_inten**	**carbon_inten**	**carbon_inten**
laglog_epu	**0.179*****	**0.320*****	0.265	−0.009
	(0.058)	(0.086)	(0.305)	(0.235)
log_realGDP	−9.949***	−14.990***	−9.896***	−15.760***
	(1.089)	(0.992)	(1.275)	(1.650)
log_population	−0.049	0.322**	6.696***	−25.467***
	(0.118)	(0.153)	(2.308)	(9.364)
share_agri	−3.199	−2.467	−18.284***	−2.661
	(2.762)	(2.830)	(6.555)	(1.861)
share_indus	−0.981	1.432	−0.438	2.980
	(0.900)	(1.574)	(1.853)	(2.922)
num_firm	1.775***	0.094	1.232**	0.688
	(0.336)	(0.174)	(0.491)	(0.662)
log_FDI	0.128**	−0.038	−0.081	0.153
	(0.053)	(0.064)	(0.058)	(0.094)
constant	148.193***	228.697***	105.804***	377.829***
	(15.018)	(15.129)	(15.589)	(49.597)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	1,056	1,011	737	418
R-squared	0.883	0.918	0.876	0.927

*Notes: Standard errors are in parenthesis, *** denotes* $p < 0.01$*, ** denotes* $p < 0.05$*, * denotes* $p < 0.1$*. FE is the fixed effect.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

TABLE 4 | Results for the heterogeneity of investment in environmental pollution control.

	(1) High	(2) Low
Variables	**carbon_inten**	**carbon_inten**
laglog_epu	**0.238*****	0.026
	(0.042)	(0.063)
log_realGDP	−13.264***	−2.612***
	(0.646)	(0.605)
log_population	0.069	0.403
	(0.138)	(0.975)
share_agri	−6.954***	0.198
	(2.576)	(0.435)
share_indus	−1.967**	0.258
	(0.894)	(0.598)
num_firm	0.857***	0.144
	(0.231)	(0.213)
log_FDI	0.024	0.053**
	(0.038)	(0.027)
constant	203.058***	38.882***
	(9.921)	(10.848)
City FE	YES	YES
Year FE	YES	YES
Observations	3,104	217
R-squared	0.892	0.997

*Notes: Standard errors are in parenthesis, *** denotes* $p < 0.01$*, ** denotes* $p < 0.05$*, * denotes* $p < 0.1$*. FE is the fixed effect.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

TABLE 5 | Results for the proportion heterogeneity of employees in the industrial sector.

	(1) High	(2) Low
Variables	**carbon_inten**	**carbon_inten**
laglog_epu	**0.243*****	0.153
	(0.053)	(0.097)
log_realGDP	−11.475***	−13.422***
	(0.828)	(0.887)
log_population	0.136	−0.138
	(0.126)	(0.355)
share_agri	−12.124***	−7.161*
	(3.934)	(4.240)
share_indus	−0.036	−3.820*
	(0.890)	(2.064)
num_firm	0.901***	0.482
	(0.220)	(0.362)
log_FDI	0.077*	−0.016
	(0.040)	(0.061)
constant	174.790***	206.425***
	(12.014)	(13.788)
City FE	YES	YES
Year FE	YES	YES
Observations	1,878	1,511
R-squared	0.903	0.897

*Notes: Standard errors are in parenthesis, *** denotes* $p < 0.01$*, ** denotes* $p < 0.05$*, * denotes* $p < 0.1$*. FE is the fixed effect.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

attaches importance to environmental pollution control, the stability and continuity of its economic policies are crucial to accelerating the green and low-carbon transformation. Contrarily, if a city does not pay much attention to environmental protection and invests less in environmental pollution control, even if the economic policy stability is

TABLE 6 | Results for the heterogeneity of science and technology expenditure.

Variables	(1) High carbon_inten	(2) Low carbon_inten
laglog_epu	**0.208******	−0.027
	(0.048)	(0.100)
log_realGDP	−9.581***	−17.417***
	(0.808)	(0.928)
log_population	0.268	0.030
	(0.189)	(0.214)
share_agri	−3.923**	−5.755*
	(1.548)	(3.124)
share_indus	−1.226	−4.995**
	(0.767)	(2.208)
num_firm	1.127***	1.066**
	(0.184)	(0.452)
log_FDI	0.070**	−0.017
	(0.034)	(0.082)
constant	143.373***	261.008***
	(12.056)	(13.611)
City FE	YES	YES
Year FE	YES	YES
Observations	2,352	1,028
R-squared	0.886	0.922

*Notes: Standard errors are in parenthesis, *** denotes* p *< 0.01, ** denotes* p *< 0.05, * denotes* p *< 0.1. FE is the fixed effect.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

worse, it will not have a significant impact on the city's carbon emission intensity.

Generally speaking, the secondary industry is the main energy consumer of a country or region and the main source of carbon emissions (An et al., 2021; Xian et al., 2022). To this end, we divide cities into high and low groups according to the proportion of employees in the secondary industry in each city. In **Table 5**, column (1) is the city group with a high proportion of secondary industry employees, and column (2) is the city group with a low proportion of secondary industry employees. It is found that the estimated coefficient of laglog_epu in column (1) of **Table 5** is significantly positive, while that in column (2) is not significant. The results demonstrate that in cities with a high proportion of secondary industry employees, urban carbon emission intensity is more susceptible to economic policy uncertainty. Conversely, cities with a low proportion of employees in the secondary industry, especially those dominated by the service industry, are not significantly affected by economic policy uncertainty in their carbon emission intensity. Important revelation can be drawn that for cities dominated by the secondary industry, special attention must be paid to the continuity and stability of the implementation of economic policies in years before and after, and the negative impact of policy fluctuations on urban green and low-carbon transformation should be avoided as far as possible.

Currently, more and more studies have shown that the level of urban innovation is one of the important factors affecting urban carbon emissions (Chen and Ma, 2021; Cheng et al., 2021; Xu et al., 2021). Therefore, according to the science and technology expenditure of each city, all cities are divided into two groups with high and low investment in science and technology expenditure. The regression results of the two are demonstrated in columns (1) and (2) in **Table 6**. The results show that the estimated coefficient of laglog_epu in column (1) is significantly positive, while that in column (2) is insignificant. It suggests that the greater the investment in urban innovation, the more significant the impact of economic policy changes on the urban carbon emission intensity. Conversely, if the city's innovation investment is less, the city's carbon emission intensity will be less sensitive to the economic policy uncertainty. From this, it can be inferred that urban innovation investment is also one of the important factors affecting the response of urban carbon emissions to economic policy uncertainty. Moreover, cities with more investment in innovation need local governments to maintain consistency and stability of economic policies to reduce the negative impact of economic policy uncertainty on urban green and low-carbon transformation.

4.3 Robustness Checks

In this paper, three methods are adopted to carry out the robustness test. The first is regression using balanced panel data. The second is to change the way the explained variables are represented, that is, to replace the carbon emission intensity with the total amount of urban carbon emissions. The third method is to use instrumental variables to address endogeneity and missing variables.

In the full sample, there are 312 prefecture-level cities that existed continuously from 2001 to 2017, which constitute a balanced panel dataset with a total of 5,304 observations. Column (1) in **Table 7** is the regression result of the balanced panel data. It can be found that excluding the influence of unbalanced panel data, the estimated coefficient of laglog_epu is 0.246 and significantly positive, which is almost consistent with the estimated coefficient of the baseline regression (0.244), indicating that our empirical results are robust. Column (2) in **Table 7** replaces the explained variable with the logarithm of the city's total carbon emissions (log_carbon). The estimated coefficient of laglog_epu is 0.004 and is significantly positive, showing that the increase of urban economic policy uncertainty will increase the total carbon emissions of the city, that is, frequent fluctuations in economic policies are not conducive to green and low-carbon transformation.

Column (3) in **Table 7** is the estimation result by using instrumental variables. Although we find that the increase of urban economic policy uncertainty will lead to the increase of urban carbon emission intensity, the baseline regression results cannot eliminate the impact of missing variables and potential reverse causality. Namely, the bias caused by endogeneity to the regression results cannot be excluded (Bilgili et al., 2022b) argue that there is a certain correlation between the policy uncertainty indices of different countries in the context of globalization. In this regard, this paper chooses the United States economic policy uncertainty index as the instrumental variable of China's urban economic policy uncertainty index. As is known to all that instrumental variables need to satisfy two conditions at the same time, namely correlation and exogeneity. On the one hand, many studies have found that changes in the domestic

TABLE 7 | Results for the robustness checks.

	(1) Balanced panel	(2) Carbon emissions	(3) IV estimation
Variables	carbon_inten	log_carbon	carbon_inten
laglog_epu	**0.246*****	**0.004****	3.945***
	(0.043)	(0.002)	(0.646)
log_realGDP	−12.764***	0.073***	−12.482***
	(0.640)	(0.014)	(0.292)
log_population	0.072	0.005	−0.369
	(0.145)	(0.006)	(0.286)
share_agri	−8.578***	−0.183*	−10.568***
	(2.380)	(0.101)	(2.129)
share_indus	−2.235**	0.067**	−6.884***
	(0.886)	(0.031)	(1.174)
num_firm	0.844***	0.062***	0.722***
	(0.209)	(0.008)	(0.225)
log_FDI	0.037	−0.005***	0.033
	(0.039)	(0.002)	(0.049)
constant	194.786***	1.444***	
	(9.754)	(0.206)	
City FE	YES	YES	YES
Year FE	YES	YES	YES
Cragg-Donald Wald F statistic			67.42
Anderson-Rubin Wald test			Chi-sq (1) = 82.02***
Sargan statistic			0.000
Observations	3,391	3,409	2,872
R-squared	0.883	0.991	0.190

*Notes: Standard errors are in parenthesis, *** denotes* $p < 0.01$*, ** denotes* $p < 0.05$*, * denotes* $p < 0.1$*. FE is the fixed effect.*
The bold values are intended to highlight and guide the readers, so that they can quickly and clearly find the corresponding coefficients combined with the empirical analysis of this paper.

economic policies of the United States, as a leader in the world economy, will not only directly affect the United States economic growth and transmit to the global economy, but also indirectly affect China's domestic economic policies. Therefore, there is a certain correlation between the economic policy uncertainty index between China and the United States. On the other hand, we believe that it is difficult for the United States economic policy uncertainty index to directly affect the carbon emission intensity of Chinese cities, so the United States economic policy uncertainty index, as an instrumental variable of the Chinese urban economic policy uncertainty index, satisfies the exogenous condition. Consequently, this paper obtains the economic policy uncertainty index in the United States from 2001 to 2017 from Baker's homepage (https://www.policyuncertainty.com/). Subsequently, we use the proportion of the total import and export volume of China's 31 provinces (municipalities and autonomous regions) from 2001 to 2017 to the national total import and export volume as the weight, and then multiply it by the United States economic policy uncertainty index from 2001 to 2017, to obtain the instrumental variables of economic policy uncertainty in 31 provinces (municipalities and autonomous regions) in China. Finally, the economic policy uncertainty index of the province where each city is located is taken as the urban economic policy uncertainty index, and the logarithm is taken. The estimation results of instrumental variables in column (3) of **Table 7** demonstrate that the estimated coefficient of laglog_epu is 3.945 and is significantly positive, and the regression coefficients of the remaining control variables are generally consistent with the baseline regression. The statistic value of F is 67.42, manifesting that the instrumental variable has passed the weak instrumental variable test, which means that the empirical results of this paper are reliable and robust.

5 CONCLUSION AND IMPLICATION

Meeting the net-zero target in the next three to four decades is challenging considering the fact that the global energy supply mix has not changed significantly over the last 50 years. Studies on economic policy uncertainty have mainly been on the national and sectoral levels, but until now, the impact of regional economic policy uncertainty on city's carbon emissions in China has not been examined, which is crucial for formulating China's carbon emission reduction targets and policies. Using the unbalanced panel data of 325 prefecture-level cities in China from 2001 to 2017 and the Chinese provincial economic policy uncertainty index constructed by Yu et al. (2021), this paper fills the gap by estimating whether regional economic policy uncertainty may affect city's carbon emission intensity. The main findings of this article are fourfold.

Firstly, our empirical results show that with one percentage point increase in the city's economic policy uncertainty, the city's carbon emission intensity will increase by 4.28 percentage points, and by 0.244 tons per ten thousand yuan at an absolute level. It can be seen that economic policy uncertainty is one of the factors that cannot be ignored that affects carbon emissions.

Secondly, in regions with higher levels of economic development, the impact of economic policy uncertainty on city's carbon emission intensity is more significant. The more cities invest in environmental pollution control, the more sensitive the city's carbon emission intensity is to changes in economic policy uncertainty, and the higher the economic policy uncertainty, the higher the carbon emission intensity.

Thirdly, compared with other types of cities, cities dominated by the secondary industry have a more sensitive carbon emission intensity to changes in economic policy uncertainty, and increased economic policy uncertainty will significantly increase the city's carbon emission intensity, which is not obvious in other types of cities.

Finally, the carbon emission intensity of cities with more investment in innovation is more sensitive to changes in economic policy uncertainty. Besides, the regression results of balanced panel data, the replacement of explained variables, and instrumental variables all show that the empirical results of this paper are robust and reliable.

The empirical results of this paper provide three very important policy implications for Chinese cities to accelerate the green and low-carbon transformation and achieve the "3060 target" as scheduled:

The first one is that policy makers need to be aware of the negative effect of economic policy uncertainty on carbon emissions reduction. A good solution is that top designers should maintain the stability and continuity of economic policy, which is not only useful for China, but also crucial for other developing countries. The higher the stability and continuity of the economic policy, the more helpful it is to promote the green and low-carbon transformation and gradually reduce the intensity of carbon emissions.

The second one is that governments need to notice the greater negative impact of economic policy uncertainty on the cities with the higher the level of economic development and the higher the proportion of employees in the secondary industry. For cities that are more affected, policy makers should establish a complete evaluation mechanism to reasonably evaluate the economic and social costs brought about by changes in economic policies. Among them, the environmental damage (such as increased carbon emission intensity) caused by the increase of economic policy uncertainty must be taken into account.

The third one is the implications, which drawn from the cities' study in China, are applicable to other high emissions countries (e.g., India and United States). Particularly, Economic policy uncertainty will not only bring negative impact on macroeconomic operation, but also on the ecological environment.

The shortcoming of this paper is that it does not consider the spillover effects of economic policy changes in neighboring cities between different regions, but chooses to focus on the impact of economic policy changes in Chinese provinces on the carbon emission intensity of cities within the provinces. In the future, we intend to study the spillover effects of economic policy changes across provinces and investigate the spillover effects of economic policy uncertainty on urban carbon emissions across different provinces through spatial econometric models.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

LF: Data curation; Writing- Original draft preparation; Visualization; Writing- Reviewing and Editing; YC: Funding acquisition; Writing- Reviewing and Editing; QX: Conceptualization; Methodology; Software; Writing- Reviewing and Editing; JM: Data curation; Visualization; Formal analysis.

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