How Does Economic Policy Uncertainty Affect CO2 Emissions? A Regional Analysis in China

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How does economic policy uncertainty affect CO_2 emissions? A regional analysis in China

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Abstract
More recently, the COVID-19 pandemic outbreak has created massive economic policy uncertainty (EPU). EPU and its economic fallout have been a hot topic of study, however, the impact of EPU on CO_2 emissions has been seldom addressed to date. This paper investigates the direct impact of the EPU on CO_2 emissions and indirect effect via the environmental regulation at the national and regional levels using the panel data model and provincial panel data from 2003 to 2017 in China. The empirical results show that the central region is the most special one, which all explanatory variables except energy consumption are all non-significant even at the 10% level. For other samples, there is a significant positive correlation between EPU and CO_2 emissions, whether in the national or regional level. Additionally, environmental regulation alone can achieve the purpose of curtailing carbon emissions. However, when the EPU is taken into consideration, environmental regulation exerts a significantly positive effect on CO_2 emissions, leading to unintended increase in emissions. Moreover, the Environmental Kuznets Curve (EKC) hypothesis was confirmed in the national and eastern samples, while CO_2 emissions increase monotonically as economic level grows for western datasets. Based on the overall findings, some policy implications were put forward.

Keywords CO_2 emissions · Economic policy uncertainty · Environmental regulation · Panel data models

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Abstract

More recently, the COVID-19 pandemic outbreak has created massive economic policy uncertainty (EPU). EPU and its economic fallout have been a hot topic of study, however, the impact of EPU on CO_2 emissions has been seldom addressed to date. This paper investigates the direct impact of the EPU on CO_2 emissions and indirect effect via the environmental regulation at the national and regional levels using the panel data model and provincial panel data from 2003 to 2017 in China. The empirical results show that the central region is the most special one, which all explanatory variables except energy consumption are all non-significant even at the 10% level. For other samples, there is a significant positive correlation between EPU and CO_2 emissions, whether in the national or regional level. Additionally, environmental regulation alone can achieve the purpose of curtailing carbon emissions. However, when the EPU is taken into consideration, environmental regulation exerts a significantly positive effect on CO_2 emissions, leading to unintended increase in emissions. Moreover, the Environmental Kuznets Curve (EKC) hypothesis was confirmed in the national and eastern samples, while CO_2 emissions increase monotonically as economic level grows for western datasets. Based on the overall findings, some policy implications were put forward.

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Introduction

Climate change due to global warming is one of the defining issues of our time. Global temperature has been in constant rise since the pre-industrial era. Its well-known reason is the steady climb of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2) which is now 50% higher than pre-industrial levels. The member states of the United Nations have agreed to limit the increase in the global average temperature to 1.5°C, which requires substantial worldwide commitments to achieve these goals. As the world's largest carbon emitters, China has been paid more and more attention from all over the world on the issue of how the country to reduce greenhouse gas emissions and mitigate the climate change. Clarifying the impact of factors behind carbon emissions is significant for efforts to meet this challenge.

There is an extensive body of literature that analyzes the mechanism behind carbon emissions. Its well-established root cause is the consumption of a large amount of fossil fuel energy and economic activity human-made. Ehrlich and Ehrlich (1970) first propose the Impact =Population· Affluence· Technology (IPAT) framework to analyze environmental changes affected by anthropogenic driving forces. Dietz and Rosa (1994) reformulate the IPAT framework by considering nonproportional effects of driving forces, raising the stochastic version of this model, namely, STIRPAT (stochastic impacts by regression on population, affluence and technology). The stochastic model has been actively applied to examine all other factors affecting human impact on the environment for both developed and developing countries, such as industrial structure (Dong et al. 2020, Wang et al. 2016, Yu et al. 2018), foreign direct investment (FDI) (Demena and Afesorgbor 2020, Mahadevan and Sun 2020, Shahbaz et al. 2019, Tang and Tan 2015) and urbanization (Elliott and Clement 2014, Huo et al. 2020, Khan et al. 2019, Makido et al. 2012, Yao et al. 2018).

A considerable number of studies have investigated the nexus between CO_2 emissions and economic growth. Grossman and Krueger (1991) develop Environmental Kuznets Curves (EKC) to emphasize this nexus. Resembling Kuznets Curve of inequality (Kuznets 1955), the EKC also postulates an inverted-U hypothesis. According to EKC, environmental pollution or CO_2 emissions increase as economic level grows at the beginning and then decrease after a certain turning point. Since then, with various datasets and complex econometric methods employed, the EKC has been tested extensively, but the validity of itself is debatable. In the context of the EKC framework, the nonlinear relationship can be explained by three effects, that is, income, structural and abatement effect (Jaunky 2011). The results verified in many previous studies often appear to be contradictory and inconclusive both theoretically and empirically. The empirical studies like Chiu (2012), Farhani et al. (2014) confirm the existence of the EKC. The empirical findings of Alshehry and Belloumi (2017), Baek (2015), Fernández-Amador et al. (2017), Haq et al. (2016), however, fail to provide such positive support. Moreover, Rodríguez et al. (2016) show a monotonic and positive relationship between environmental quality indicators and income. As mentioned, no clear conclusion can be drawn.

In the process of achieving green development and high-quality economic growth, environmental regulation plays an extremely important role. During the "Outline of the Thirteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China" (13th Five-Year Plan) periods, the Chinese government promulgated a series of policies to strengthen environmental protection and build the ecological civilization. The relationship between environmental regulation and CO_2 emissions has been fiercely debated in recent years. As evidenced, although the field has accumulated a well-developed literature, there is no a uniform conclusion. According to the literature, there are two perspectives on this issue, that is, the "green paradox" and "curbing effect". The concept of green paradox is first put forward by Sinn (2008), which is defined as a myriad of measures launched by politicians aimed at alleviating CO_2 emissions, eventually exacerbate the problem. Sinn attributes counter-productive policies to psychological expectation that the environmental regulation will gradually be tightened, resulting in accelerating the exploitation of fossil energy. Other researchers ascribe the emergence of the green paradox to unreasonable set of carbon taxes (Edenhofer and Kalkuhl 2011), support policies for alternative energy (van der Ploeg and Withagen 2012), policy's implementation lags (Di Maria et al. 2012) and unilateral climate policies (Sen 2016). On the contrary, other scholars argue that there is a significant positive correlation between environmental regulation and environmental pollution, which is also known as the "curbing effect" hypothesis. Zhang et al. (2017), Zhao et al. (2015) indicate that environmental regulations exert a positive effect on reducing carbon emissions. Nevertheless, some studies hold a more neutral viewpoint. Wang (2018) suggest that there is an inverted U-shaped curve relationship between environmental regulation and carbon emissions. Besides, some researchers confirmed that environmental regulations have indirect effects on carbon emission through transmission paths, such as industrial structure (Yang et al. 2020), energy structure (Wu et al. 2020), technological innovation (Cheng et al. 2017, Pei et al. 2019) and FDI (Wang et al. 2018). The influence mechanism, however, is paradoxical.

After perusing the aforementioned studies, we have found that researches on the driving forces of CO_2 emissions are relatively mature, while the macroeconomic institutional factor reflected by EPU has been neglected. EPU and its economic fallout have spurred an ongoing discussions and everlasting interest in academic field. Resembling the concept of risk, EPU refers to the inability of economic entities to forecast the timing, content, and potential economic consequences of policy decisions (Gulen and Ion 2015). Driven mainly by unpredictable political cost, EPU is an inevitable by-product of policy-making (Pastor and Veronesi 2012). While, it's a daunting task to measure the overall level of EPU in the economy. A news-based index proxy for EPU developed by Baker et al. (2016) (henceforth BBD) makes it possible to capture aggregate economic policy uncertainty. Due to publicly available and scientific measure of the uncertainty present in the economy, the BBD index is widely accepted. Moreover, a coherent body of empirical research on the topic of this index has been conducted.

Understanding exactly how sensitive EPU is to CO_2 emissions is critically important for efforts to curtail emissions. However, there is a dearth of empirical literature on how EPU directly or indirectly affects CO_2 emissions. Based on US sector data, Jiang et al. (2019) implement a novel parametric test of Granger causality to assess the impact of EPU on CO_2 emissions and found that there is a Granger-causality running from the US EPU to carbon emissions. Pirgaip and Dincergok (2020) employ a bootstrap panel Granger causality test to investigate the causal relationship between EPU and energy consumption and CO_2 emissions in G7 countries. They argued that EPU has adverse effects on energy saving and emission reduction. Adedoyin and Zakari (2020) examine the role of EPU played in the nexus between energy consumption, economic and CO_2 emissions in the UK. The results indicate that EPU plays a critical role in the effort of mitigating CO_2 emissions. Additionally, Adams et al. (2020) using data from economies characterized by resource-rich but crisis-prone demonstrate that there is a significant association between geopolitical risk, EPU, energy consumption, economic growth and CO_2 emissions in the long-run. This implies that higher levels of EPU adversely affect carbon abatement. This finding is consistent with the result of Anser et al. (2021). By constructing China provincial EPU index, Yu et al. (2021) indicate that China's provincial EPU level exerts a significantly positive impact on manufacturing firms' carbon emission intensity. The empirical analysis results show that manufacturing firms incline to choose traditional cheaper and dirty energy when the level of uncertainty rising. Besides, Abbasi and Adedoyin (2021) indicate that economic policy uncertainty has an insignificant impact on China's CO_2 emissions.

The present paper contributes to the previous literature as follows. First, we account for EPU in the environmental regulation–CO_2 emissions nexus to examine the interaction effects of EPU. Understanding the impact of institutional factors behind carbon emissions is a matter of utmost significance to realize a low-carbon economy. Second, previous studies have neglected the regional heterogeneity in China's CO_2 emission. The paper analyzes the interaction effects between core variable components based on relevant data of 30 provinces in China from 2003 to 2017. Accordingly, the objective of the study is to clarify how EPU directly affects CO_2 emissions and elucidate how the EPU affects the relationship between environmental regulation and CO_2 emissions. Based on panel data methods and STIRPAT model, this research takes EPU into account and examines the direct or indirect effect of EPU on CO_2 emissions.

The paper is structured as follows: Section 2 introduces the theoretical background and hypothesis of the study, Section 3 presents the data and methods. Section 4 demonstrates the empirical results and discussions. Section 5 concludes alongside with policy implications.

Theoretical background and hypothesis

More recently, the COVID-19 pandemic outbreak has created massive economic uncertainty (Jordà et al. 2020). Without question, the EPU is significant to the economic system. EPU has dampening impact both at macro level, i.e. economic growth (Baker et al. 2016) and at micro level, i.e. corporate investments (Akron et al. 2020, Gulen and Ion 2015) , corporate innovation (He et al. 2020, Xu 2020), household consumption (Aaberge et al. 2017, Levenko 2020) and stock market (Arouri et al. 2016, Das et al. 2019). In all, uncertainty reshapes the environment in which the economic entities operate. Besides, when the external environment changes, the decision of economic entities that link to carbon emissions is altered. To summarize, we speculate that EPU may have an impact on CO_2 emissions.

Actually, the EPU has harmful effect on the whole economic and impeded the recovery from recession (Baker et al. 2016). The depressed economic situation inevitably leads to consumers curbing household consumption and enterprises postponing corporate investment. With the economic condition changed, the demand for energy consumption will be affected. Traditional cheaper energy, for instance, coal and oil would be chosen by more industries due to sluggish economic situation (Jiang et al. 2019, Yu et al. 2021). Undoubtedly, the more cheap and dirty fossil fuels energy consumed, the more carbon emissions. In addition, the level of uncertainty has a certain degree of impact on energy prices, which could affect consumers' energy choices. Balcilar et al. (2017) imply that EPU is an important driver of oil price volatility and there is an asymmetric connection between uncertainty and oil returns. Yang (2019) demonstrates that oil price shocks are significantly influenced by EPU and the causality relationship between them intensifies as time scales increase. Olanipekun et al. (2019) show that there is an asymmetric causal relationship between gasoline prices and EPU in the sampled countries. On the one hand the reduction in consumer production and living caused by higher level of EPU has partly reduced carbon emissions, on the other hand the use of more cheap and dirty energy increases carbon emissions. The net effects are unclear.

A plethora of works explore that the economic policy-related uncertainty depresses corporate investment (Chen et al. 2019, Dibiasi et al. 2018, Liu and Zhang 2020). What is more, higher level of uncertainty encourages firms to increase their cash holdings (Cheng et al. 2018, Demir and Ersan 2017, Phan et al. 2019). On the basis of the real option theory, corporate investment projects are irreversible to varying degrees and usually costly, economic policy uncertainty increases the value of the waiting option, so firms become more cautious and prefer to delay investment until getting more information for decision making, in the face of greater uncertainty (Bernanke 1983, Pindyck 1991). The main contributory paths of EPU affecting the corporate investment are attributed to financial market frictions (Liu et al. 2020a). Higher uncertainty increases external financing costs and the debt default risk. The investment of renewable energy industry for example hydropower, wind, and biomass has the nature of higher degree of irreversibility, which usually have the characteristics of larger initial investment scale and longer investment return cycle. That is, renewable energy's investment lead to higher sunk costs and renewable energy enterprises inevitably delay investment when economic policy uncertainty higher. There is no doubt that the decrease in investment, especially in the renewable energy industry, has increased carbon emissions.

Furthermore, according to signal theory, the increase of carbon information disclosure can reduce the burden of relevant government and effectively promote energy saving and emission reduction (Connelly et al. 2011). However, firms have more incentive to reduce the transparency of carbon information disclosure when the EPU is at high level. By incorporating difference-in-difference (DID) estimation, Pan et al. (2020) find that policy uncertainty has a more significant inhibition effect on corporate environmental information disclosure. Beyond question, a reduction in carbon disclosure will increase carbon emissions.

Based on the foregoing analytic mechanisms commented, this study proposes the following hypothesis.

Hypothesis1a: The EPU index has a negative correlation with CO_2 emissions.

Hypothesis1b: The EPU index has a positive correlation with CO_2 emissions.

As briefly analyzed in the introduction, the influencing mechanism between environmental regulation and CO_2 emissions is paradoxical. Undoubtedly, the unpredictability of policy changes, including environmental policies is a major source of uncertainty. With high level of uncertainty, the attention on green development from government will be distracted, resulting in environmental protection policies executed poorly. The governments' determination to reduce emissions may be doubted, which in turn leads to the efforts for carbon abatement by enterprises relaxed, eventually resulting in the increase of emissions. We infer that the indirect effect of EPU on CO_2 emissions may be through environmental regulation, that is to say, EPU exerts interaction effects on the environmental regulation–CO_2 emissions nexus. Guo et al. (2019a) contend that uncertainty has a significantly effect on environmental policy making. They argued that both underestimation and overestimation of uncertainties make against to formulate a reasonable carbon mitigation design by policy makers. Lecuyer and Quirion (2019) argue that high level of uncertainty has a positive incentive effect on renewable energy subsidies effectiveness, while these subsidies are not welfare-improving at the low level of uncertainty. Considering the forward-looking policy uncertainty, Contreras and Platania (2019) put forward a zero mean reverting model to estimate the effectiveness of the London Environment Strategy. Against this backdrop, the EPU is a key determinant in understanding the impact of environmental regulation on CO_2 emission. Based on the discussion above, this study puts forward the following hypothesis:

Hypothesis 2: EPU plays an important role in moderating the relationship between environmental regulation and CO_2 emissions.

Data and methods

Data

In the present study, considering the availability and completeness of the data, 30-provincal panel data from 2003 to 2017 in China are investigated. Given that the CO_2 emissions are heterogeneous in different regions, these 30 provincial-level administration regions can be divided into three groups, namely, eastern, central, and western regions, according to the level of economic and social development. The three economic zones are at different stages of economic development. Due to this, the subsequent analysis is conducted at both national and regional level.

The CO_2 emission data were collected from the China Emission Accounts and Datasets (CEADS) website. Sponsored by domestic and international professional bodies research institutes, such as National Natural Science Foundation of China, Science and Technology Research Council UK, CEADs devotes to China's emission accounting methods and applications (Liu et al. 2020b). The carbon emission datasets published by CEADs are characterized by fully open access, multi-scale coverage and free to download. In addition to the traditional energy consumption carbon emission database, CEADs database also covers the detailed data of carbon emissions from industrial processes, including cement production, lime production, glass, and so on. The emission data is accurate and most up-to-date, effectively avoiding measurement errors.

The regional difference of CO_2 emissions can be clearly seen from Fig.2. The fluctuation trend of emissions is generally on the rise. National CO_2 emissions increase roughly one and a half times throughout the study period. Due to superior in resource endowment, CO_2 emissions in the eastern region has been in a dominant position in 2003–2017. The western region's emission levels have exceeded those of the central region since 2013. Since 2011, the growth of CO_2 emissions has become slower. Apparently, CO_2 emissions in China has been effectively controlled.

Based on (Baker et al. 2013b), the BBD index is a weighted average of three components, namely, the news-based component, the tax component and the forecaster disagreement component. The weights are one-half, one-sixth and one-third, respectively. BBD go to great lengths to verify the BBD index is a reliable and accurate picture of EPU. According to the newspaper-based methods, the EPU indices have been constructed for major economies including China. Based on the South China Morning Post (SCMP), Hong Kong's leading English-language newspaper, Baker et al. (2013b) develop a monthly EPU index for China, running from January 1995 to the present. The index may have some limitations. The Hong Kong-based newspaper may not overall picture the level of EPU in China and only one newspaper in the sample may magnify measurement error that could induce a bias in empirical analysis. To conquer those shortcomings, following BBD approach, Davis et al. (2019) (henceforth DLS) construct monthly indices of EPU for China by using two mainland Chinese newspapers: the Renmin Daily and the Guangming Daily.

The two indices are compared in Fig. 1. Both indices look like a sensible proxy for true policy-related economic uncertainty. In addition, the data show that the EPU curve of China is not smooth, and the phenomena of large growth and the sharp decline occurring alternately. They tend to move together with spikes around events that are ex ante predicable to increase uncertainty, such as financial crises, stimulus package, elections. Currently, these two indices rose to historic highs after the global pandemic. However, there are significant divergences between two indices. As a result, this study takes the DLS index as the benchmark indicator.

In this paper, we use cost-based environmental regulation indices as the proxy variable for the level of environmental regulations (Guo et al. 2019b, Hu and Wang 2020, Lanoie et al. 2008, Wang et al. 2019, Wu et al. 2020, Yang et al. 2020). We adopt the ratio of industrial pollution governance expenditures collected by each province to its industrial added value (denoted as ER) as the environmental regulation variable. It is easy to find that the cost-based index focus on the expenditure (input) of pollution control in each province. There is a positively correlation between cost-based index and the enforcement of government environmental regulation. The larger the value of the index, the greater environmental regulation intensity. Therefore, pollution control expenditure or treatment investments can well reflect the environmental regulation intensity.

To eliminate the impact of price factors, all variables related to the price index, including environmental regulation, per capita GDP, are converted to the constant 2000 price. Energy consumption is expressed by the total energy consumption of each province at the end of the year. In order to be consistent with the time horizon, the monthly Chinese DLS EPU index is converted into the annual EPU index by the arithmetic average method. The 30-province shares the same average EPU index. In addition, this study takes Chinese BBD EPU index as the auxiliary index measuring the level of economic policy uncertainty to test results robustness.

The data sources are described in Table 1. Table 2 shows the descriptive statistics for all variables.

Methods

The primary purpose of this paper is to shed light on the mechanisms how uncertainty affects the CO_2 emissions. By examining the direct or indirect effect of EPU on CO_2 emissions, we establish the following models based on panel data methods and STIRPAT model. CO_2 emissions were selected as the explanatory variable. Economic policy uncertainty and environmental regulation were the core explanatory variable.

$$CO2 = f(RGDP, RGDP2, ENC, EPU, ER)$$

$$\ln CO2_{it} = \alpha_0 + \beta_1 \ln RGDP_{it} + \beta_2 RGDP2_{it} + \beta_3 \ln ENC_{it} + \beta_4 \ln EPU_{it} + \beta_5 \ln ER_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (1)$$

$$CO2 = f(RGDP, RGDP2, ENC, EPU, ER, EPU * ER)$$

$$\ln CO2_{it} = \alpha_0 + \beta_1 \ln RGDP_{it} + \beta_2 RGDP2_{it} + \beta_3 \ln ENC_{it} + \beta_4 \ln EPU_{it} + \beta_5 \ln ER_{it} + \beta_6 \mathrm{lnEPUER}_{it} + \lambda_{\mathrm{t}} + \mu_{\mathrm{i}} + \varepsilon_{it} \quad (2)$$

Equation (1) is constructed to elucidate the directly effect of EPU on CO_2 emissions. Based on equation (1), equation (2) introduced the concept of $EPU_{it} * ER_{it}$, namely the interacted items of EPU and ER to examine the interaction effects of EPU on the environmental regulation–CO_2 emissions nexus. To ensure the linearity of the model and eliminate the heteroscedasticity phenomenon, logarithmic processing is carried out for all variables.

Herein, $\ln CO_{2it}$ means the carbon emission per capita; lnRGDP and lnRGDP2 denote Real Gross Domestic Product per capita in logarithms and its squared term. The quadratic term of RGDP is incorporated in the models to test the EKC hypothesis in the context of China. lnENC is energy consumption; lnER expresses environmental regulation; lnEPU represents economic policy uncertainty, where subscripts *i* and *t* denote the *i-th* province and the *t-th* year, respectively. α_0 is the constant term; β_1, $\beta_2 \ldots \beta_6$ are the evaluation coefficients, with β_5 and β_6 being the focus of interest coefficients in this study. λ_t and μ_i are time fixed effects and individual fixed effects respectively. ε_{it} is the residual error term.

Results and discussion

Table 3 presents the Pearson correlation matrix to capture the intensity of the correlation between the variables and indicate no high correlations. As it is shown, both the EPU and the level of environmental regulation are positively and significantly correlated with CO_2 emission, while the relationship between them are negative. Besides, energy consumption and environmental regulation is insignificantly related.

In this paper, 30-province panel data from 2003 to 2017 in China are employed. Normally, in terms of short panel data, there are three types of estimation method: pooled regression, fixed effects model and random effects model. This paper performs F test and Hausman (1978) test to choose the most appropriate estimation method. The F test is run to inspect individual specific effects with the null hypothesis, that is all $\mu_i = 0$. The lower the p-value of the F-test statistic, the higher the significance level. With the null hypothesis is rejected, the estimator of fixed effects model is more efficient than the pooled regression. The Hausman test is applied to determine whether to choose the fixed effects model or the random effects model. Similarly, the larger Hausman test value means that the corresponding p-value is smaller than preset significance levels. The null hypothesis should be rejected and a fixed effects model established. Table 4 reports the F test results. The empirical results of Hausman test are shown in Table 5.

As shown in Table 4 and Table 5, the results of the F test and the Hausman test implied that the null hypothesis was strongly rejected, suggesting that the fixed effects model should be selected to examine the directly or indirectly effect of EPU on CO_2 emissions for the whole nation and the three regions.

This paper decomposes the effect of the EPU on CO_2 emissions from the national and regional level, respectively. We mainly focus on the empirical results of Equation 2. The empirical results are reported in Table 6. The columns present the results of the whole dataset and the three regional datasets, respectively.

As shown in Table 6, the empirical results of the fixed effect estimation at the national level show that all the explanatory variables are statistically significant at 1% level (Eq. (2)). While in model 1, all explanatory variables are statistically significant except for the EPU. Due to natural logarithmic form taken in this model, the coefficients of the explanatory variables could be directly explained as elasticities. According to the estimation results of Eq. (2), the EPU positively increases the carbon emissions. A 1% increase of uncertainty would increase emissions 0.3326% in China when other variables remain constant. The estimate results conform to both our expectations and the findings of previous studies (Adams et al. 2020, Pirgaip and Dincergok 2020). They argued that EPU has adverse effects on emission reduction. In accord with economic intuition, economic policy uncertainty disrupts economic situation, inhibiting household consumption and corporate investment, especially in the renewable energy industry. All of consequences do harm to economic restructuring, industrial upgrading and green innovation. Depressed economic environment drives enterprises to choose traditional cheaper and dirty energy for production, leading to increased carbon emission. Ultimately, the EPU exert negative effect on CO_2 emissions. Other possible explanation for the negative correlation was that higher uncertainty has a more significant inhibition effect on corporate environmental information disclosure. The less environmental disclosure information, the worse it is for carbon reduction. Thereby, hypothesis 1a was verified.

Our results show that environmental regulation was negatively correlated with CO_2 emissions. This implies that environmental regulation tools meet the basic requirements of emissions reduction at the national level. Through a forced mechanism, the improvement of environmental regulation is conductive to mitigate emissions. China's current legal and supervision systems on environmental protection have being more and more adequate with various regulations and measures promulgated. This result is in accord with the findings of Pei et al. (2019), Zhang et al. (2017). Furthermore, this paper uses the interactive term (EPU*ER) to capture the effect of uncertainty on the functional mechanisms of environmental regulation. Meanwhile the signs of interactive term are positive and statistically significant, indicating that under the influence of uncertainty, environmental regulations have significantly promoted CO_2 emissions and that a green paradox occurs. The possible reasons why EPU exerts positive impact upon the environmental regulation-CO_2 emissions nexus is that the priority for governments is economic stability rather than environmental conservation or other environmental policies under high level of uncertainty, resulting in the standards of environmental policy implementation relaxed and carbon emissions increased. Therefore, hypothesis 2 is verified.

For the control variables, the elasticity of energy consumption is the greatest (0.8495), indicating that a 1% increase in energy consumption level would lead to 0.8495% increase in CO_2 emissions. GDP growth rate are positively associated with CO_2 emissions.

By judging from the quadratic term of per capita GDP, the regression coefficients are negative at the significance level of 1%. In other words, the environmental Kuznets curve (EKC) theory holds.

Considering the typical regional differences in China, the relationship between considered variables may also have regional heterogeneity characteristics. Thus, we should analyze the effects of the EPU upon emissions at the region level. Compared with the national aggregate case, the eastern region has similar findings. The influences of variables appear to be greater due to high economic intensity and population density in this region. In the eastern region, all the independent variables are statistically significant at the 1% level (Model 4). The elasticity of energy consumption is 0.5923, which is the lowest in the sample selected. Environmental regulation passes t-test with elasticity of -0.418. That is to say, for every 1% increase in environmental regulations, carbon emissions fall by 0.418%. The EPU index has a significant role in promoting eastern CO_2 emissions, taking the value of 0.5802. From the perspective of the moderating effect of uncertainty, the coefficient of interaction term between EPU and environmental regulation is significantly positive, indicating that uncertainty can increase CO_2 emissions from environmental regulation.

As shown in Column 6, the central region is quite different. It is worth noting that all explanatory variables except energy consumption are all non-significant even at the 10% level. One possible explanation is that the heterogeneity of sample distribution causes insignificance of most variables. Owing to fast urbanization and industrialization process, the elasticity of energy consumption in the central region is the highest (0.9600). In the western region, energy consumption is the biggest element with elasticity of 0.8456, followed by uncertainty. The interactive term (EPU*ER) has similar story to that of the nation level and the eastern region. The findings indicate that environmental regulation can effectively mitigate CO_2 emissions without consideration of uncertainty. However, when the EPU taken into consideration, environmental regulation exerts a significantly positive effect on CO_2 emissions, leading to unintended increase in emissions. Environmental regulations and the EPU are statistically significant with elasticity of - 0.3006 and 0.5060, respectively. It indicates that the increase of the intensity of environmental regulations is conducive to improve carbon emission reduction, while the positive sign of uncertainty means that high level of EPU would definitely lead to more carbon emissions. Both environmental regulation and EPU index are lower than that of the eastern case. In a word, it can be found from Table 6 that uncertainty and the interactive term (EPU*ER) have significantly contributed to the increase in CO_2 emissions, while environmental regulations intensity shows a significantly negative association with CO_2 emissions, whether in the nation level or the regions.

The variable GDP per capita presents a positive and significant effect on emissions for eastern and western regions except for central region for which the relation isn't significant. In the eastern region, the coefficient of GDP per capita is the largest (0.7243), which is much higher than other samples. It suggests that there is a strong link between economic growth and CO_2 emissions. The coefficient of the quadratic term of GDP per capita is negative and statistically significant in the eastern region, while it is statistically nonsignificant in the central and western regions. This means that the results in the eastern region is in line with the theory of EKC, however the inverted U-shaped relationship between economic growth and emissions cannot hold any more in the central and western regions.

Robustness test

In this study, the auxiliary economic policy uncertainty variable (EPU2) developed by Baker et al. (2016) is used for the robustness test. The results of robust test are shown in Table 7. The sign and significance of these variables' coefficients have seldom changed. Overall, the findings are consistent with the results of Table 6. Therefore, it can be concluded that the aforementioned results of empirical analysis are relatively robust.

Despite informative findings yielded, this study has some limitations that are worth noting. First of all, this study employed a same set of EPU indices as proxy for Chinese provinces uncertainty level, which is not in line with the reality. For better estimating the impact of economic policy uncertainty on CO_2 emissions, more rational uncertainty accounting for Chinese provinces level is expected in future studies. Moreover, economic policy uncertainty could affect CO_2 emissions through many channels, from which this paper only considers the elements of environmental regulation, and other factors such as energy consumption, foreign direct investment would be studied in future research. Second, the cost-based environmental regulation indices only reveal one aspect of environmental governance. Therefore, a more reasonable and comprehensive index to fully reflect the level of environmental regulations would become increasingly important. Furthermore, this study only employed a conventional econometric method, further research would take spatial spillover effects into consideration. The exploration of spatial spillover effects is conducive to the in-depth study of the driving forces behind CO_2 emissions (Feng et al. 2020, Hu and Wang 2020, Meng et al. 2017).

Conclusions and policy implications

Using panel data of 30 provinces of China from 2003 to 2017, this study empirically analyzes the direct impact of EPU and the indirect impact of environmental regulation on CO_2 emissions. The main conclusions can be summarized as follows.

At the national level, the EPU positively increases the carbon emissions and environmental regulation alone is negatively correlated with CO_2 emissions. However, under the influence of the EPU, environmental regulations significantly promote carbon emissions, causing a green paradox. That is to say, economic policy uncertainty provided interaction effects between environmental regulations and CO_2 emissions. The mechanism of the interaction effects was that the high level of uncertainty will lead to the current environmental regulations executed poorly, ultimately promoting CO_2 national emissions.

At the region level, the central region is the most special one. All explanatory variables except energy consumption are all non-significant even at the 10% level. The eastern and western regions have the similar findings to the whole nation. Moreover, the results demonstrate that the re-examination of the EKC hypothesis is inconclusive. Kuznets relationship between economic growth and CO_2 emissions for the national and eastern samples was confirmed. While CO_2 emissions rises monotonically as GDP grows for western datasets.

Given the main results we obtained, the related policy implications can be drawn. First and foremost, this study demonstrated that high level of uncertainty exerts negative impact upon mitigating emissions, resulting in environment deteriorate. For this reason, the government should do their best to minimize the adverse effects of uncertainty. Unexpected spike in the level of economic policy uncertainty could not affect the credibility of government. The determination to environmental conservation and emission abatement of government would not be shaken even under high levels of uncertainty. Necessary supportive measures should be taken into consideration to decrease uncertainty and maintain transparency and stability of policies.

Besides, environmental regulations play an important role in the emission abatement. The intensity of environmental regulations must be appropriate. An overly restrictive emission-reduction policy would be counterproductive. Besides, the environmental regulations should not be one size fits all, due to the discrepancies of economic development and energy resource endowments. Therefore, different regions should implement different environmental policies according to regional conditions. Moreover, these regulations should be applied without hampering policy stability, since economic policy uncertainty goes against to the effectiveness of environmental regulations and the achievement of carbon mitigation targets. In addition, environmental protection is not just a matter for the government. The role of public participation and supervision should be emphasized. Local residents should improve the awareness of energy conservation and low-carbon lifestyle. Furthermore, there is a need to strengthen the interregional cooperation and communication on carbon reduction experiences and practices to maximize technology spillovers effects. All regions should work hand in hand to tackle the issue.

Last but not least, the empirical findings uncovered the adverse effect of energy consumption on CO_2 emissions. Accordingly, the government concerned should promote the use of renewable energy or clean energy, for instance, nuclear power, hydropower, wind power to optimize energy consumption structure and lessen the dependence on fossil fuel energy. Meanwhile, the government should increase the fiscal support and stimulate capital investment for low-carbon technologies innovation to improve energy efficiency, decoupling economic growth from environmental pollution.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by YL and ZPZ. The first draft of the manuscript was written by ZPZ and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

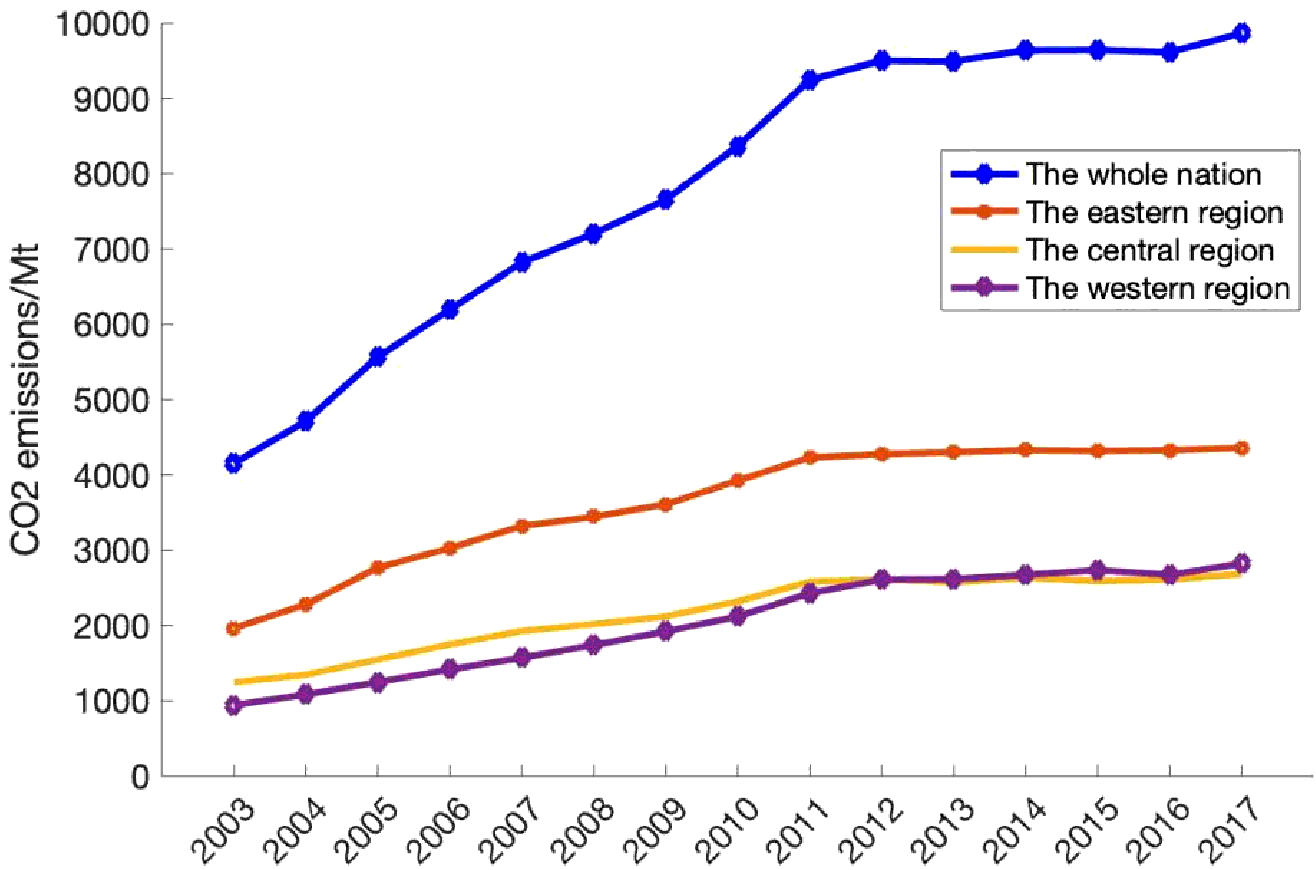

Figure 1

Changes in China's national and regional CO2 emissions from 2003 to 2017

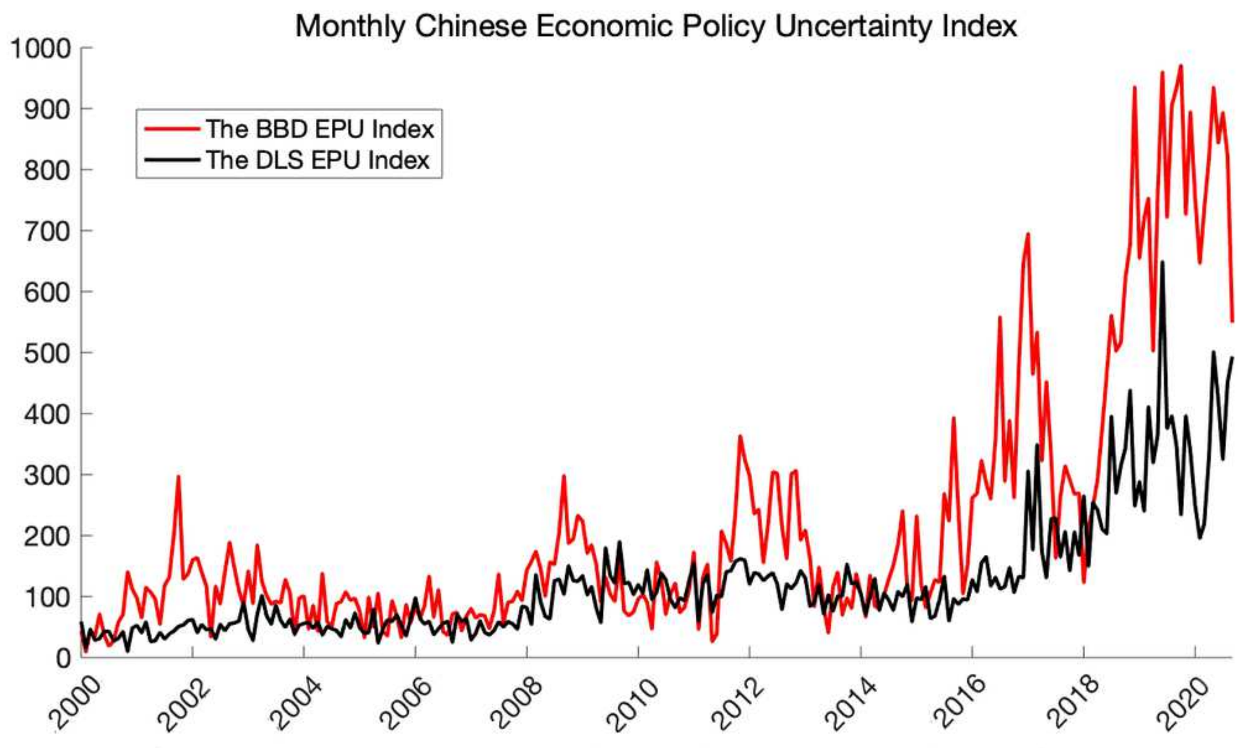

Figure 2

The figure shows monthly Chinese policy-related economic uncertainty Index from January 2000 to October 2020