

Article

Does Economic Policy Uncertainty Affect CO₂ Emissions? Empirical Evidence from the United States

Qing Wang ^{1,*}, Kefeng Xiao ² and Zhou Lu ³¹ Department of Finance, Economics and Management School, Wuhan University, Wuhan 430072, China² Economics and Management School, Wuhan University, Wuhan 430072, China; kkefeng.xiao@gmail.com³ School of Business, Tianjin University of Commerce, Tianjin 300134, China; luzhou59@tjcu.edu.cn

* Correspondence: 2016101050042@whu.edu.cn

Received: 10 October 2020; Accepted: 25 October 2020; Published: 2 November 2020



Abstract: This paper aims to examine the effects of economic policy uncertainty (measured by the World Uncertainty Index—WUI) on the level of CO₂ emissions in the United States for the period from 1960 to 2016. For this purpose, we consider the unit root test with structural breaks and the autoregressive-distributed lag (ARDL) model. We find that the per capita income promotes CO₂ emissions in the long run. Similarly, the WUI measures are positively associated with CO₂ emissions in the long run. Energy prices negatively affect CO₂ emissions both in the short run and the long run. Possible implications of climate change are also discussed.

Keywords: CO₂ emissions; economic policy uncertainty; World Uncertainty Index; ARDL model; United States

1. Introduction

In today's world, climate change is one of the leading problems which has the potential to harm sustainable economic performance both in developing and developed countries. The main reason for climate change is the atmospheric concentration of carbon dioxide and other greenhouse gases. These greenhouse gases lead to global warming, and global warming changes the climate around the globe. Therefore, it is essential to understand the driving factors of CO₂ emissions. Our paper aims to examine the determinants of CO₂ emissions, and special interest is given to the level of economic policy uncertainty, which is measured by the World Uncertainty Index (WUI) in [1].

CO₂ emissions are strongly related to economic activities and the burning of fossil fuels [2]. Previous papers have indicated that there is a significant impact of income (which is usually measured by the per capita gross domestic product (GDP)) on environmental indicators [3]. However, income can decrease the level of environmental pollution in developed countries as the policymakers in these countries can consider health and other issues that can be more important than the level of per capita income or economic performance. Besides this, environmental pollution and greenhouse gases, which lead to global warming and climate change, threaten sustainable economic growth both in developed and developing economies.

A higher level of per capita income or economic growth will increase the level or the growth rate of CO₂ emissions. However, policymakers should be more careful about CO₂ emissions when per capita GDP increases. At this stage, policymakers can provide a more environment-friendly production process, and this structural transformation will reduce the growth rate of CO₂ emissions. This view has been modeled as the Environmental Kuznets Curve (EKC) by [2,4]. The empirical results of [2,4] indicate that higher economic performance will cause an increase in the level of greenhouse gas emissions until a developing country experiences a specific level of per capita GDP. Then, greenhouse gas emissions

will start to reduce. To put it differently, the EKC model suggests an inverted U-shaped impact of per capita GDP on the level of CO₂ emissions [5].

On the other hand, along with the economic performance, energy usage can affect CO₂ emissions. Specifically, higher energy consumption leads to a higher level of CO₂ emissions. At this stage, previous papers have used different indicators of energy usage, and they have mostly considered the oil price to include the price effect in EKC modeling [3]. Different from previous papers, we use a broader and new measure of price effect and use the economy-wide energy price index in real prices in [6]. Therefore, we control for both the income effect and the price effect in the EKC modeling. These indicators should be significantly related to the level of CO₂ emissions in the United States, which is one of the leading CO₂ emitters in the world [7].

At this stage, we include the level of economic policy uncertainty (measured by the WUI) as a new driving factor of CO₂ emissions in the United States. In other words, we extend the EKC model with the WUI and address a possible omitted variable bias. Indeed, researchers have indicated that uncertainty decreases investments [8–11] and leads to a decline in international trade [12]. However, the effects of uncertainty shocks on CO₂ emissions seem to be neglected by empirical papers. We suggest that economic policy uncertainty can negatively or positively affect the level of CO₂ emissions in an open economy. Our hypothesis is based on the fact that an open economy consists of the consumption of energy-intensive products and energy investments. At this stage, a higher level of WUI can cause a decline in the consumption of energy and pollution-intensive products; thus, CO₂ emissions will be reduced as the WUI increases. We can label this effect the “consumption effect”.

On the other hand, a higher level of WUI can harm the investments in green energy and renewable energy projects; thus, CO₂ emissions will be increased as the WUI increases. We can label this effect as the “investment effect (substitution effect)”. Naturally, the impact of the WUI on CO₂ emissions depends on whether the “consumption effect” or the “investment effect” is dominant, where the latter is dominant in the case of the United States between 1960 and 2016. We suggest that economic policy uncertainty should be considered in EKC modeling, and it can provide important implications to sustain economic growth and to change the pattern of climate change via economic performance.

Overall, our study analyzes the determinants of CO₂ emissions in the United States between 1960 and 2016. At this stage, we consider the WUI, which is introduced by [1]. Here, the authors of [1] measure the level of economic policy uncertainty in 143 developing and developed countries, and they show that this new uncertainty measure is negatively related to international trade and investments. At this juncture, the main objective of our study is to examine the impact of the WUI on CO₂ emissions in the United States. Following previous papers on EKC modeling, we control for the income effect (which is measured by per capita GDP) and the price effect (which is measured by the novel index for real energy prices in [6] in modeling the level of CO₂ emissions in the United States, i.e., the largest economy of the globe [13]. To the best of the authors’ knowledge, this paper is the first research in the empirical literature to examine the effects of the WUI on CO₂ emissions following the EKC model. According to the empirical results, per capita income and economic policy uncertainty are positively related to CO₂ emissions in the United States in the long run. Besides this, we observe that energy prices decrease the level of CO₂ emissions in the United States both in the short run and the long run.

The rest of the paper is organized as follows. Section 2 provides a brief review of the literature for previous papers on the determinants of CO₂ emissions in the United States. Section 3 describes the data and empirical models and explains the estimation procedure. Section 4 discusses the empirical results with possible implications. Section 5 is the concluding remarks.

2. Previous Papers on the Determinants of CO₂ Emissions in the United States

There are various studies to examine the determinants of CO₂ emissions in the United States. Along with the income effect and the price effect within the EKC model, various additional controls have been included. Financial development, foreign direct investment (FDI), trade openness, and urban population have been included as additional controls within the EKC model (see, e.g., [7]). At this

stage, we review the papers which have used the time-series techniques and focus on only the case of the United States. For a detailed review of the related literature on other countries, one can refer to the recent study of [3]. We also review the papers, which focus on the aggregate level of CO₂ emissions in the United States at the country level. Note that there are also several studies which focus on regional level data in the United States (see, e.g., [14,15]). Besides this, there are several papers which focus on sectoral level data in the United States (see, e.g., [16]).

In terms of these conditions, for example, the authors of [17] show that the income effect is not statistically significant. Still, the price effect significantly affects the level of CO₂ emissions in the United States for the period from 1960 to 2000. Using the data for the period from 1960 to 2007, the authors of [18] also find that income is not a significant driver of CO₂ emissions. While nuclear energy can significantly decrease CO₂ emissions, renewable energy does not affect CO₂ emissions in the United States. The authors of [7] use data for the period from 1960 to 2010 in the United States to examine the determinant factors of CO₂ emissions. The authors find that energy consumption and urban population increase the level of CO₂ emissions, while international trade decreases CO₂ emissions. Financial development does not significantly affect environmental degradation. Income is also negatively related to CO₂ emissions in the country. The authors of [19] also observe that the EKC model is not valid in the United States from 1980 through 2014. Besides this, renewable energy consumption reduces the level of CO₂ emissions; however, non-renewable energy consumption increases environmental degradation. The authors of [20] investigate the validity of the EKC model in the United States by using data for the period from 1960 to 2016. The authors find that income, biomass energy consumption, and international trade decrease the level of CO₂ emissions. Oil price does not have a significant impact on CO₂ emissions in the country. The authors of [21] also show that energy consumption and foreign direct investments increase CO₂ emissions in the United States. However, trade openness reduces CO₂ emissions in the country.

The authors of [22] also state that the level of CO₂ emissions in the United States declined by 12% between 2007 and 2016. The authors show that economic growth is negatively related to CO₂ emissions. At this stage, improvements in energy efficiency, an increase in eco-friendly investments, and the rise of labor productivity are the main channels driving the negative impact of economic growth on CO₂ emissions in the United States.

On the other hand, there are a few papers which investigate the impact of economic policy uncertainty on environmental indicators. For example, the authors of [16] use sectoral level data to examine the relationship between economic policy uncertainty and the growth rate of CO₂ emissions in the United States. The authors find that the growth rate of CO₂ emissions in the industrial, residential, and transportation sectors are significantly affected by economic policy uncertainty. However, the direction of the relationship is unclear. Besides this, the authors of [23] analyze the causal relationships among CO₂ emissions, economic policy uncertainty, and energy consumption in the United Kingdom for the period from 1985 to 2017. The authors find that economic policy uncertainty decreases CO₂ emissions in the short run, but there is no relationship in the long run. The authors of [24] use data from 1985 to 2017 in the United States to examine the effects of energy intensity on CO₂ under economic policy uncertainty. The authors find that economic policy uncertainty promotes the detrimental impact of energy intensity on CO₂ emissions.

Overall, various papers indicate that the validity of the income effect and the price effect is arguable, but we should include them into the estimations of the empirical model. There are also a few studies analyzing the effects of economic policy uncertainty on CO₂ emissions. Still, there is no study which uses the WUI of [1] and the real energy price index of [6]. To the best of our knowledge, our paper provides the first evidence for the effects of the WUI on CO₂ emissions in the empirical literature.

3. Data, Model, and Estimation Procedure

3.1. Data

We examine the drivers of CO₂ emissions in the United States. The sample covers the annual data from 1960 to 2016. The start and the end dates of the empirical analysis are related to the availability of the data at the country level (note that energy price data at the global level can also be downloaded from https://ycharts.com/indicators/energy_index_world_bank#:~:text=Energy%20Price%20Index%20is%20at,30.71%25%20from%20one%20year%20ago). The dependent variable is the CO₂ emissions (metric tons) per capita in logarithmic form (LnCO₂_PC). The related data are obtained from [13]. We also use various explanatory variables. Specifically, GDP per capita (measured by the real 2010 USD prices) in logarithmic form (LnGDP_PC) captures the income impact in CO₂ emission function. The data are collected from [13]. Energy prices (measured by the economy-wide index in real prices) in the logarithmic form (LnENPR) are also included in the model estimations. LnENPR captures the price impact in CO₂ emission function, and the related data are obtained from the online appendix of [6].

Furthermore, we consider two measures of the World Uncertainty Indices (WUI_T2 and WUI_T6), and the data are obtained from [1]. We use the annual data, which are the averages of quarterly data. It is noteworthy that the authors of [1] introduce the WUI for 143 countries from the 1950s to 2020. The related indices are calculated by counting the frequency of the uncertainty (or its variant) in the Economist Intelligence Unit (EIU) country reports. The authors use the total number of words to normalize the WUI measures. A higher value of indices indicates a higher level of uncertainty. Refer to worlduncertaintyindex.com for details of the WUI measures. The measure of the WUI_t2 is the simple relative index in a given period. However, the measure of the WUI_t6 provides the three-quarter weighted moving average of the WUI. For example, 2019Q4 = (2019Q4 × 0.6) + (2019Q3 × 0.3) + (2019Q2 × 0.1)/3. Therefore, the WUI_t6 provides a more smoothed version of the WUI. According to [1], the WUI_t6 should be a benchmark measure for country-level analysis. We use both measures of the WUI to check the robustness of the empirical results for different measures of the WUI. Table 1 provides the descriptive statistics. Finally, we provide a correlation matrix in Table 2.

Table 1. Descriptive statistics (1960–2016).

Indicator	Definition	Unit	Form	Data Source	Mean	Std. Dev.	Max.	Min.
CO ₂ Emissions per Capita	LnCO ₂ _PC	Metric Tons	Logarithmic	[13]	2.940	0.094	2.740	3.113
GDP per Capita	LnGDP_PC	Real 2010 USD	Logarithmic	[13]	10.40	0.328	9.773	10.86
Energy Price	LnENPR	Index in Real Price	Logarithmic	[6]	4.366	0.227	4.001	4.757
World Uncertainty Index	WUI_T2	Index	Level	[1]	0.133	0.088	0.012	0.381
World Uncertainty Index	WUI_T6	Index	Level	[1]	0.044	0.028	0.004	0.113

Table 2. Correlation matrix (1960–2016).

Indicator	LnCO ₂ _PC	LnGDP_PC	LnENPR	WUI_T2	WUI_T6
LnCO ₂ _PC	1.000	–	–	–	–
LnGDP_PC	–0.089	1.000	–	–	–
LnENPR	–0.128	0.583	1.000	–	–
WUI_T2	–0.493	0.202	0.130	1.000	–
WUI_T6	–0.488	0.199	0.129	0.973	1.000

The findings in Table 2 show that there is a negative correlation between the level of CO₂ emissions and all explanatory variables. The correlation between the WUI and CO₂ emissions is –0.49. Per capita income is positively correlated with energy prices (0.58) and the WUI measures (0.2). Besides this, the energy price index is also positively correlated with the WUI measures (0.13). These results indicate that there is no potential issue of multicollinearity among explanatory variables. There is a very high correlation between both measures of the WUI (0.97). Given that we separately use these two measures of the WUI, there will be no problem of multicollinearity. Finally, the quantile–quantile (Q–Q) graphs of the variables are illustrated in Figure 1.

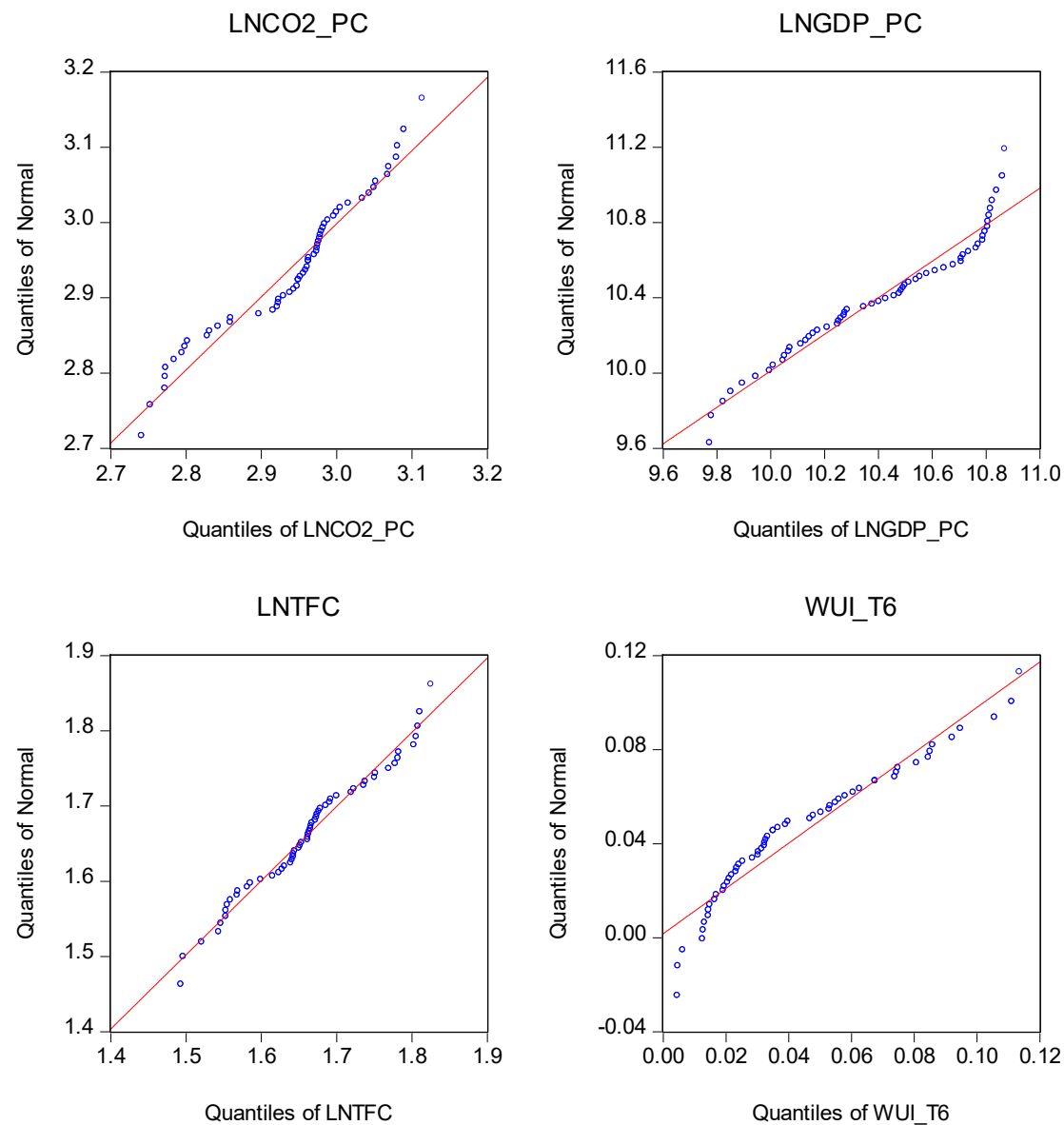


Figure 1. Quantile-quantile (Q-Q) plots of the variables.

3.2. Empirical Model

We consider a well-known EKC model in the literature (e.g., [25,26]), and we aim to explain the drivers of per capita CO₂ emissions. We include the per capita income, and energy prices are the main determinants of CO₂ emissions. We also suggest that the WUI is a significant driver of CO₂ emissions. At this stage, we can use the following function for an extended EKC model:

$$\text{CO2_PC}_t = f(\text{GDP_PC}_t^{\alpha_1}, \text{ENPR}_t^{\alpha_2}, \text{WUI}_t^{\alpha_3}) \quad (1)$$

The function in Equation (1) can be written in model form, as such:

$$\text{LnCO2_PC}_t = \alpha_0 + \alpha_1 \text{LnGDP_PC}_t + \alpha_2 \text{LnENPR}_t + \alpha_3 \text{WUI}_t + \varepsilon_t \quad (2)$$

In Equations (1) and (2), LnCO2_PC_t is the per capita CO₂ emissions, LnGDP_PC_t is the per capita income, LnENPR_t is the index of energy prices, WUI_t the World Uncertainty Index. Except for the WUI, the indicators are defined in logarithmic form. ε_t denotes an error term.

Following previous papers, we expect that $\alpha_1 > 0$ and $\alpha_2 < 0$. The EKC hypothesis demonstrates that $\alpha_1 > 0$ since there should be a positive impact of income on CO₂ emissions. Besides this, higher energy prices lead to lower CO₂ emissions ($\alpha_2 < 0$).

Finally, the impact of economic policy uncertainty on CO₂ emissions can be negative or positive. This evidence is due to the issue that an open economy consists of energy-intensive products and energy investments. Higher economic policy uncertainty can lead to a reduction in the consumption of energy and pollution-intensive products, and thus, CO₂ emissions will be declined. This effect can be labeled as a “consumption effect” ($\alpha_3 < 0$). However, higher economic policy uncertainty can decrease the investments in green energy and renewable energy projects; thus, CO₂ emissions will be increased. This effect can be labeled as an “investment effect” ($\alpha_3 > 0$). Naturally, the impact of economic policy uncertainty on CO₂ emissions depends on whether the “consumption effect” or the “investment effect” is dominant. Surely, we must obtain a statistically significant coefficient of α_3 .

3.3. Estimation Procedure

First, we apply the unit root test of [27], which accounts for structural breaks in the level. Second, we utilize the bounds tests of [28] for the cointegration in the model with level term. We must reject the null hypothesis of “no cointegrating relationship in the time-series”. In other words, we should find a significant cointegration. Here, the critical values in [28,29] are considered, where the latter corrects small samples. Third, we estimate the short-run and the long-run coefficients in Equation (2) via the Autoregressive distributed lag (ARDL) model, introduced by [30]. Therefore, we estimate the following regression, where the per capita CO₂ emissions are the dependent variable:

$$\begin{aligned} \Delta \text{LnCO2PC}_t = & \alpha_0 + \sum_{i=1}^n \alpha_1 \text{LnCO2PC}_{t-k} + \sum_{i=0}^n \alpha_2 \Delta \text{LnGDP_PC}_{t-k} + \sum_{i=0}^n \alpha_3 \Delta \text{LnENPR}_{t-k} \\ & + \sum_{i=0}^n \alpha_4 \Delta \text{WUI}_{t-k} + \beta_1 \text{LnCO2PC}_{t-1} + \beta_2 \text{LnGDP_PC}_{t-1} \\ & \beta_3 \text{LnENPR}_{t-1} + \beta_4 \text{WUI}_{t-1} + \beta_5 D2007 + \varepsilon_{1t} \end{aligned} \quad (3)$$

In Equation (3), Δ represents the first difference operator, ε_{1t} denotes the error term, α ($i = 1, 2, 3$, and 4) are the long-run parameters, and β ($i = 1, 2, 3, 4$, and 5) are the short-run parameters in the ARDL model. Besides this, $D2007$ represents the dummy variable for structural breaks, which captures the period after 2007. The date is based on the findings of the unit root test of [27]. Following [31], we also report the following diagnostics of the ARDL estimations: Breusch–Godfrey serial correlation, Ramsey Reset model specification, Harvey heteroscedasticity tests as well as Cumulative Sum (CUSUM) and Cumulative Sum of Square (CUSUMSQ) tests for parameter stability.

We also utilize the long-run and the short-run Vector Error Correction (VEC) Granger Causality/Block Exogeneity Wald test. The following Equation contains the procedure of the related causality test:

$$\begin{aligned} \begin{bmatrix} \Delta \text{LnCO2PC}_{2t} \\ \Delta \text{LnGDP_PC}_t \\ \Delta \text{LnENPR}_t \\ \Delta \text{WUI}_t \end{bmatrix} = & \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \end{bmatrix} + \begin{bmatrix} \gamma_{11,1} & \gamma_{12,1} & \gamma_{13,1} & \gamma_{14,1} \\ \gamma_{21,1} & \gamma_{22,1} & \gamma_{23,1} & \gamma_{24,1} \\ \gamma_{31,1} & \gamma_{32,1} & \gamma_{33,1} & \gamma_{34,1} \\ \gamma_{41,1} & \gamma_{42,1} & \gamma_{43,1} & \gamma_{44,1} \end{bmatrix} \begin{bmatrix} \Delta \text{LnCO2PC}_{t-1} \\ \Delta \text{LnGDP_PC}_{t-1} \\ \Delta \text{LnENPR}_{t-1} \\ \Delta \text{WUI}_{t-1} \end{bmatrix} + \dots + \\ & \begin{bmatrix} \gamma_{11,i} & \gamma_{12,i} & \gamma_{13,i} & \gamma_{14,i} \\ \gamma_{21,i} & \gamma_{22,i} & \gamma_{23,i} & \gamma_{24,i} \\ \gamma_{31,i} & \gamma_{32,i} & \gamma_{33,i} & \gamma_{34,i} \\ \gamma_{41,i} & \gamma_{42,i} & \gamma_{43,i} & \gamma_{44,i} \end{bmatrix} \begin{bmatrix} \Delta \text{LnCO2PC}_{t-i} \\ \Delta \text{LnGDP_PC}_{t-i} \\ \Delta \text{LnENPR}_{t-i} \\ \Delta \log \text{WUI}_{t-i} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} \text{ECT}_{t-1} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \\ \varepsilon_{4,t} \end{bmatrix} \end{aligned} \quad (4)$$

In Equation (4), ECT_{t-1} is the lagged error correction term, which represents the speed of adjustment to the long-run equilibrium. $\varepsilon_{1,t}$, $\varepsilon_{2,t}$, $\varepsilon_{3,t}$, and $\varepsilon_{4,t}$ are random error terms, which are independent and identically distributed (i.i.d.).

4. Empirical Results and Discussion

4.1. Unit Root Test

First, we provide the results of the unit root test of [27], which are assumed a break on the level in Table 3.

Table 3. Unit root test of [27].

Indicator	Test Statistic and Lag	Break	Indicator	Test Statistic and Lag	Conclusion
LnCO ₂ PC	−3.725 (3)	2007	ΔLnCO ₂ PC	−6.466 ***	I(1)
LnGDP_PC	−5.101 (1)	2007	ΔLnGDP_PC	−6.645 ***	I(1)
LnENPR	−2.845 (1)	1973	ΔLnENPR	−6.191 ***	I(1)
WUI_T2	−7.448 *** (0)	2000	ΔWUI_T2	−	I(0)
WUI_T6	−7.179 *** (0)	2000	ΔWUI_T6	−	I(0)

Notes: The findings, which are assumed a break on the level, are reported. Null hypothesis: the indicator follows a unit root process. Lags, which are selected by Bayesian Information Criteria (BIC), are in (). *** $p < 0.01$.

According to the findings in Table 3, LnCO₂PC, LnGDP_PC, LnENPR have a unit root, and their first differences are stationary. Therefore, these variables follow an I(1) process. On the other hand, the WUI_t2 and the WUI_t6 follow a stationary process; therefore, they follow the I(0) process. Since all variables do not follow an I(1) process, the traditional cointegration tests should not be considered. In light of these findings, we follow [32] and utilize the bounds cointegration test for cointegration and estimate ARDL model coefficients.

4.2. Bounds Test for Cointegration Analysis

We report the results of the bounds test for the model with the level in Table 4. We observe that the related F-statistics for the two models are higher than the critical values, which are provided by [28,29]. As a result, the null hypothesis (there is no level cointegration) is rejected. We observe the significant cointegration relationship among the related indicators.

Table 4. Bounds tests for cointegration analysis.

Bounds Tests for Cointegration	F-Statistic	Optimal Lag
Model 1: LnCO ₂ PC–LnGDP_PC–LnENPR–WUI_T2	5.317 **	1
Model 2: LnCO ₂ PC–LnGDP_PC–LnENPR–WUI_T6	4.343 **	1
Panel B: Critical Values Provided by [28]	Lower Bound, I(0)	Upper Bound, I(1)
1% Significance Level	3.74	5.06
5% Significance Level	2.86	4.01
10% Significance Level	2.45	3.52
Panel C: Critical Values Provided by [29]	Lower bounds, I(0)	Upper bounds, I(1)
1% Significance Level	4.24	5.72
5% Significance Level	3.06	4.33
10% Significance Level	2.57	3.71

Notes: The model with the level is considered. The optimal lag length is selected by the BIC. The null hypothesis: there is no level cointegration. ** $p < 0.05$.

4.3. Long-Run Estimates of the ARDL Model

Then, we estimate the long-run coefficients of the ARDL model, and the results are reported in Table 5. Initially, the ARDL model has suitable misspecification and stable parameters, and there are no problems in terms of serial correlation and heteroscedasticity. Specifically, the Breusch–Godfrey test shows that there is no serial correlation problem in residuals. The Ramsey Reset test indicates that there is no misspecification problem in the model. According to the results of the Harvey Heteroskedasticity test, the variances of the models are homoscedastic. Finally, CUSUM and CUSUMSQ tests show that the coefficients of regressions are stable over time, and possible structural breaks are correctly modeled.

Table 5. Long-run coefficients of the Autoregressive Distributed Lag (ARDL) model estimations.

Dependent Variable: LnCO ₂ PC	Model 1 (with WUI_T2)	Model 2 (with WUI_T6)
Regressors	Long-Run ARDL Models (3, 0, 0, 0, 1)	Long-Run ARDL Models (3, 0, 0, 0, 1)
LnCO ₂ PC _{t-1}	1.015 *** (0.103)	1.005 *** (0.094)
LnCO ₂ PC _{t-2}	−0.328 ** (0.142)	−0.252 * (0.141)
LnCO ₂ PC _{t-3}	0.286 *** (0.073)	0.230 ** (0.091)
LnGDP_PC _t	0.641 *** (0.211)	0.594 *** (0.215)
LnENPR _t	−0.069 *** (0.018)	−0.081 *** (0.029)
WUI _t	−0.034 (0.032)	−0.035 (0.106)
WUI _{t-1}	0.063 ** (0.028)	0.171 ** (0.081)
Break Dummy	−0.010 (0.009)	−0.012 (0.010)
Constant Term	0.396 ** (0.172)	0.358 ** (0.172)
Adjusted R ²	0.957	0.958
F-statistic	133.7	110.9
Breusch–Godfrey Serial Correlation F-test	0.025 [0.974]	0.238 [0.788]
Ramsey Reset F-test	0.138 [0.712]	0.255 [0.615]
Harvey Heteroskedasticity F-test	0.966 [0.479]	0.822 [0.618]
Cumulative Sum Test	Stable ($p < 0.05$)	Stable ($p < 0.05$)
CUSUM of Squares Test	Stable ($p < 0.05$)	Stable ($p < 0.05$)

Notes: Dependent variable is LnCO₂PC_t. The standard errors are in (), and the probability values are in [].

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$.

According to the results in Table 5, the lagged dependent variables are statistically significant up to three lags (LnCO₂PC_{t-1}, LnCO₂PC_{t-2}, and LnCO₂PC_{t-3}). Coefficients, which represent the structural break (dummy variable for the period after 2007), are statistically insignificant. The long-run income impact, which is measured by log current per capita GDP (LnGDP_PC_t), is found as inelastic and positive (0.64 for the first model and 0.59 for the second model). Following this evidence, we can conclude that income promotes CO₂ emissions. The long-run price impact, which is captured by the index of real energy price (LnENPR_t), is also inelastic but negative (−0.069 for the first model and −0.081 for the second model). This evidence indicates that energy prices decrease CO₂ emissions in the long run.

Finally, the long-run impact of economic policy uncertainty, which is measured by the indices of the WUI_{t2} and the WUI_{t6}, is found as elastic. Note that the current WUI measures have negative coefficients, but they are statistically insignificant. The lagged WUI measures positively affect CO₂ emissions, and the coefficients are elastic (0.063 for the first model and 0.171 for the second model). This evidence implies that higher economic policy uncertainty in the previous year in the United States leads to higher CO₂ emissions in the current year.

4.4. Short-Run Estimates of the ARDL Model

We also provide the findings of the short-run coefficients for the ARDL model estimations in Table 6. Note that the coefficient of the Error Correction Term (ECT_{t-1}) in the lagged form is obtained as −0.026 ($p < 0.01$) and −0.016 ($p < 0.01$) for the first model and the second model, respectively. This evidence implies that the level of CO₂ emissions in the United States converges in the long-run equilibrium by a low-level speed of adjustment ([32]), via the channels of per capita income, energy price, and economic policy uncertainty.

Table 6. Short-run coefficients of the ARDL model estimates.

Short-Run ARDL Model (2, 0, 0, 0, 0)	ΔLnCO ₂ PC _t	Short-Run ARDL Model (2, 0, 0, 0, 0)	ΔLnCO ₂ PC _t
ΔLnCO ₂ PC _{t-1}	0.042 (0.095)	ΔLnCO ₂ PC _{t-1}	0.022 (0.098)
ΔLnCO ₂ PC _{t-2}	−0.286 (0.199)	ΔLnCO ₂ PC _{t-2}	−0.230 (0.202)
ΔLnGDP_PC _t	0.641 *** (0.133)	ΔLnGDP_PC _t	0.594 *** (0.135)
ΔLnENPR _t	−0.072 *** (0.015)	ΔLnENPR _t	−0.062 * (0.031)
ΔWUI_T2 _t	−0.034 (0.023)	ΔWUI_T6 _t	−0.035 (0.075)
Break Dummy	−0.028 (0.017)	Break Dummy	−0.041 (0.030)
Constant Term	0.396 *** (0.077)	Constant Term	0.358 *** (0.076)
ECT _{t-1}	−0.026 *** (0.004)	ECT _{t-1}	−0.016 *** (0.003)
Adjusted R ²	0.669	Adjusted R ²	0.674
F-statistic	22.46 ***	F-statistic	16.68 ***
Durbin–Watson	1.918	Durbin–Watson	1.807

Notes: Dependent variable is ΔLnCO₂PC_t. The standard errors are in (). *** $p < 0.01$ and * $p < 0.10$.

The findings in Table 6 show that the lagged dependent variables are statistically insignificant up to two lags ($\Delta \text{LnCO}_2\text{PC}_{t-1}$ and $\Delta \text{LnCO}_2\text{PC}_{t-2}$). Coefficients of the structural breaks are also statistically insignificant. The short-run income impact, which is measured by $\Delta \text{LnGDP_PC}_t$, is obtained as inelastic and positive (0.64 for the first model and 0.59 for the second model). Therefore, income also increases CO_2 emissions in the short run. The short-run price impact, which is measured by ΔLnENPR_t , is also inelastic and negative (-0.072 for the first model and -0.062 for the second model). This evidence means that energy prices also reduce CO_2 emissions in the short run. Finally, the short-run impact of economic policy uncertainty, which is measured by the indices of the WUI_t2 and the WUI_t6, is found as negative but statistically insignificant. This evidence shows that economic policy does not significantly affect CO_2 emissions in the United States in the short run.

4.5. VEC Granger Causality

We also provide the findings of the long-run and the short-run VEC Granger Causality/Block Exogeneity Wald test in Table 7. The findings indicate that the long-run causality for both models of CO_2 emissions is statistically significant ($p < 0.01$). This evidence is in line with the results of long-run ARDL model estimates.

Table 7. VEC Granger Causality/Block Exogeneity Wald Tests.

Dependent Variable: $\Delta \text{LnCO}_2\text{PC}_t$	Chi-Square Test Statistics	Chi-Square Test Statistics
Whole Model	14.86 *** [0.0019]	14.16 *** [0.0027]
$\Delta \text{LnGDP_PC}$	0.163 [0.6863]	0.039 [0.8424]
ΔLnENPR	14.35 *** [0.0002]	11.89 *** [0.0006]
$\Delta \text{WUI_T2}$	0.144 [0.7035]	—
$\Delta \text{WUI_T6}$	—	0.132 [0.7157]

Notes: The optimal number of lag lengths is selected by the BIC. Probability values are in brackets. *** $p < 0.01$.

In terms of short-run causality, only the energy prices cause CO_2 emissions in the United States. The income and economic policy uncertainty measures do not significantly cause CO_2 emissions in the short run. Therefore, the results for the income coefficient in the short-run ARDL model estimates are not robust enough to run a different econometric method. Overall, income and economic policy uncertainty increase CO_2 emissions only in the long run, while energy prices are negatively related to CO_2 emissions both in the short run and the long run.

4.6. Discussion of Results and Potential Implications

Our results show that there is a positive impact of income on CO_2 emissions in the long run. This evidence implies that our extended EKC-based model is valid in the United States in the long run. However, short-run income (economic growth) does not affect environmental pollution, and this evidence should be expected in developed countries, such as the United States. Besides this, energy prices yield lower CO_2 emissions in the United States both in the short run and the long run, as it is expected. It seems that energy prices are only the determinant of CO_2 emissions in the United States both in the short run and the long run. This issue also means that the future levels of CO_2 emissions in the United States can be predicted from its previous levels as well as from per capita income, energy prices, and economic policy uncertainty measures.

We also find that economic policy uncertainty measures are positively related to CO_2 emissions in the United States in the long run. We can suggest that decreasing the level of economic policy uncertainty can promote a more environment-friendly transformation process in the United States, i.e., the structural transformation from fossil-fuel energy to renewable energy in the production. At this stage, the COVID-19 pandemic is creating a remarkable rise in uncertainty in economic policies in the United States. Our results also indicate that this issue can make the climate change problem worse. Overall, stable and transparent economic policies can help to mitigate the level of CO_2 emissions in the United States in the long run, and this is our novel contribution to the existing empirical literature.

Note that our findings are obtained by the whole CO₂ emissions in the United States, and this issue is the limitation of our study. Of course, we should enhance our knowledge of the level of CO₂ emissions for each sector in the United States to understand better how economic policy uncertainty affects environmental pollution in the country.

5. Concluding Remarks

In this paper, we investigate the effects of economic policy uncertainty, which is measured by the WUI of [1] on CO₂ emissions in the United States over the period from 1960 to 2016. We extended the EKC approach by incorporating the WUI. For this purpose, we initially run the unit root test of [27] with structural breaks and then the bounds cointegration analysis. Following the results of the initial tests, we estimate the ARDL model of [30]. We also utilize the VEC Granger Causality test to check the robustness of the short-run and the long-run coefficients. To the best of the authors' knowledge, this paper is the first research to examine the effects of the WUI on CO₂ emissions.

The empirical results are as follows. First, the per capita income increases CO₂ emissions in the long run. Second, the index of energy prices decreases the level of CO₂ emissions both in the short run and in the long run. Third, the WUI indices are positively associated with CO₂ emissions in the long run, and this finding is the novel evidence of the existing environmental economics literature.

Future papers for investigating the effects of economic policy uncertainty on CO₂ emissions can focus on other large economies, such as Brazil, China, and India. Finally, our paper uses the novel index of energy prices of [6] at the aggregated level. At this stage, future studies can use different types of energy prices (e.g., coal or oil prices) in developing or developed countries.

Author Contributions: Conceptualization, Q.W., and K.X.; methodology, Z.L.; software, Q.W.; validation, K.X., Q.W., and Z.L.; formal analysis, Q.W.; investigation, K.X.; resources, K.X.; data curation, Z.L.; writing—original draft preparation, Q.W.; writing—review and editing, K.X.; visualization, K.X.; supervision, Z.L.; project administration, Z.L. All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the financial supports from the Philosophy & Social Science Fund of Tianjin City, China ("Prompting the Market Power of Tianjin City's E-commerce Firms in Belt & Road Countries: A Home Market Effect Approach").

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ahir, H.; Bloom, N.; Furceri, D. *The World Uncertainty Index*; Policy Research (SIEPR) Working Paper; No. 19-027; Stanford Institute for Economic, Stanford University: Stanford, CA, USA, 2019.
2. Grossman, G.M.; Krueger, A.B. Economic Growth and the Environment. *Q. J. Econ.* **1995**, *110*, 353–377. [[CrossRef](#)]
3. Shahbaz, M.; Sinha, A. Environmental Kuznets Curve for CO₂ Emissions: A Literature Survey. *J. Econ. Stud.* **2019**, *46*, 106–168. [[CrossRef](#)]
4. Grossman, G.M.; Krueger, A.B. *Environmental Impacts of a North American Free Trade Agreement*; National Bureau of Economic Research (NBER) Working Paper; No. 3914; NBER: Cambridge, MA, USA, 1991.
5. Dinda, S. Environmental Kuznets Curve Hypothesis: A Survey. *Ecol. Econ.* **2004**, *49*, 431–455. [[CrossRef](#)]
6. Liddle, B.; Huntington, H. Revisiting the Income Elasticity of Energy Consumption: A Heterogeneous, Common Factor, Dynamic OECD & Non-OECD Country Panel Analysis. *Energy J.* **2020**, *41*, 207–229.
7. Dogan, E.; Turkekul, B. CO₂ Emissions, Real Output, Energy Consumption, Trade, Urbanization and Financial Development: Testing the EKC Hypothesis for the USA. *Environ. Sci. Pollut. Res.* **2016**, *23*, 1203–1213. [[CrossRef](#)] [[PubMed](#)]
8. Bernanke, B.S. Irreversibility, Uncertainty, and Cyclical Investment. *Q. J. Econ.* **1983**, *98*, 85–106. [[CrossRef](#)]
9. Bloom, N. The Impact of Uncertainty Shocks. *Econometrica* **2009**, *77*, 623–685.
10. Dixit, A.K.; Dixit, R.K.; Pindyck, R.S. *Investment under Uncertainty*; Princeton University Press: Princeton, NJ, USA, 1994.
11. Rodrik, D. Policy Uncertainty and Private Investment in Developing Countries. *J. Dev. Econ.* **1991**, *36*, 229–242. [[CrossRef](#)]

12. Novy, D.; Taylor, A.M. Trade and Uncertainty. *Rev. Econ. Stat.* **2020**, *102*, 749–765. [\[CrossRef\]](#)
13. World Bank. *The World Development Indicators*; The World Bank: Washington, DC, USA, 2020.
14. Roach, T. A Dynamic State-level Analysis of Carbon Dioxide Emissions in the United States. *Energy Policy* **2013**, *59*, 931–937. [\[CrossRef\]](#)
15. Tzeremes, P. Time-varying Causality between Energy Consumption, CO₂ Emissions, and Economic Growth: Evidence from US States. *Environ. Sci. Pollut. Res.* **2018**, *25*, 6044–6060. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Jiang, Y.; Zhou, Z.; Liu, C. Does Economic Policy Uncertainty Matter for Carbon Emission? Evidence from US Sector Level Data. *Environ. Sci. Pollut. Res.* **2019**, *26*, 24380–24394. [\[CrossRef\]](#)
17. Soytaş, U.; Sari, R.; Ewing, B.T. Energy Consumption, Income, and Carbon Emissions in the United States. *Ecol. Econ.* **2007**, *62*, 482–489. [\[CrossRef\]](#)
18. Menyah, K.; Wolde-Rufael, Y. CO₂ Emissions, Nuclear Energy, Renewable Energy, and Economic Growth in the US. *Energy Policy* **2010**, *38*, 2911–2915. [\[CrossRef\]](#)
19. Dogan, E.; Ozturk, I. The Influence of Renewable and Non-renewable Energy Consumption and Real Income on CO₂ Emissions in the USA: Evidence from Structural Break Tests. *Environ. Sci. Pollut. Res.* **2017**, *24*, 10846–10854. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Shahbaz, M.; Solarin, S.A.; Hammoudeh, S.; Shahzad, S.J.H. Bounds Testing Approach to Analyzing the Environment Kuznets Curve Hypothesis with Structural Breaks: The Role of Biomass Energy Consumption in the United States. *Energy Econ.* **2017**, *68*, 548–565. [\[CrossRef\]](#)
21. Shahbaz, M.; Gozgor, G.; Adom, P.K.; Hammoudeh, S. The Technical Decomposition of Carbon Emissions and the Concerns about FDI and Trade Openness Effects in the United States. *Int. Econ.* **2019**, *159*, 56–73. [\[CrossRef\]](#)
22. Wang, Q.; Jiang, X.T.; Ge, S.; Jiang, R. Is Economic Growth Compatible with a Reduction in CO₂ Emissions? Empirical Analysis of the United States. *Resour. Conserv. Recycl.* **2019**, *151*, 104443. [\[CrossRef\]](#)
23. Adedoyin, F.F.; Zakari, A. Energy Consumption, Economic Expansion, and CO₂ Emission in the UK: The Role of Economic Policy Uncertainty. *Sci. Total Environ.* **2020**, *738*, 140014. [\[CrossRef\]](#)
24. Ulucak, R.; Khan, S.U.D. Relationship between Energy Intensity and CO₂ Emissions: Does Economic Policy Matter? *Sustain. Dev.* **2020**, *28*, 1457–1464.
25. Narayan, P.K.; Saboori, B.; Soleymani, A. Economic Growth and Carbon Emissions. *Econ. Model.* **2016**, *53*, 388–397. [\[CrossRef\]](#)
26. Peng, H.; Tan, X.; Li, Y.; Hu, L. Economic Growth, Foreign Direct Investment and CO₂ Emissions in China: A Panel Granger Causality Analysis. *Sustainability* **2016**, *8*, 233. [\[CrossRef\]](#)
27. Perron, P. Further Evidence on Breaking Trend Functions in Macroeconomic Variables. *J. Econom.* **1997**, *80*, 355–385. [\[CrossRef\]](#)
28. Pesaran, M.H.; Shin, Y.; Smith, R.J. Bounds Testing Approaches to the Analysis of Level Relationships. *J. Appl. Econom.* **2001**, *16*, 289–326. [\[CrossRef\]](#)
29. Narayan, P.K. The Saving and Investment Nexus for China: Evidence from Cointegration Tests. *Appl. Econ.* **2005**, *37*, 1979–1990. [\[CrossRef\]](#)
30. Pesaran, M.H.; Shin, Y. An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. In *Econometrics and Economic Theory in the 20th Century*; Strom, S., Ed.; The Ragnar Frisch Centennial Symposium: Cambridge, UK, 1999; pp. 371–413.
31. Gozgor, G.; Can, M. Does Export Product Quality Matter for CO₂ Emissions? Evidence from China. *Environ. Sci. Pollut. Res.* **2017**, *24*, 2866–2875. [\[CrossRef\]](#)
32. Narayan, P.K.; Smyth, R. What Determines Migration Flows from Low-Income to High-Income Countries? An Empirical Investigation of Fiji-U.S. Migration 1972–2001. *Contemp. Econ. Policy* **2006**, *24*, 332–342. [\[CrossRef\]](#)

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).