Applying a dynamic ARDL approach to the Environmental Phillips Curve (EPC) hypothesis amid monetary, fiscal, and trade policy uncertainty in the USA

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Year: 2022

Version: Accepted version

Please cite the original version:

Bhowmik, R., Syed, Q. R., Apergis, N., Alola, A.A. & Gai, Z. (2022). Applying a dynamic ARDL approach to the Environmental Phillips Curve (EPC) hypothesis amid monetary, fiscal, and trade policy uncertainty in the USA. *Environmental Science and Pollution Research* 29(10), 14914-14928. https://link.springer.com/article/10.1007/s11356-021-16716-y

Applying a dynamic ARDL approach to the Environmental Phillips Curve (EPC) hypothesis amid monetary, fiscal, and trade policy uncertainty in the USA

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Abstract

It is well known that unemployment and environmental degradation are two critical issues across the globe. However, there is extended dearth of the literature that explores the nexus between unemployment and environmental degradation. Kashem and Rahman (2020) put forward the Environmental Phillips Curve (EPC) hypothesis, which depicts a negative relationship between unemployment and environmental degradation. This study further explores the validity of the EPC hypothesis in the case of the US. It also investigates the impact of monetary policy uncertainty (MU), fiscal policy uncertainty (FU), and trade policy uncertainty (TU) on carbon dioxide emissions. To this end, the analysis employs the novel methodology of dynamic ARDL model. The results document that EPC does not hold in the short-run, but it does in the long-run. Furthermore, both in the short- and long-run, MU escalates CO_2 emissions, while FU plunges emissions in both the short- and long-run. Finally, TU does not alter the level of CO_2 emissions.

Keywords: Environmental Phillips Curve; monetary policy uncertainty; fiscal policy uncertainty; trade policy uncertainty; CO_2 emissions; Dynamic ARDL model

Introduction

Global warming, climate change, and environmental degradation are repeatedly cited as the emerging concerns for humanity nowadays. These factors are mainly responsible for the rise in global temperature and extreme weather conditions. Moreover, food insecurity has also been escalating due to climate change and environmental degradation. In addition, these environmental issues have further detrimental effects on human health (Warner et al., 2010; Azam, 2016; Kompas et al., 2018; Gorus and Aslan, 2019; Khavarian et al., 2019), while climate change also impacts production and consumption activities (Alshehry and Belloumi, 2015; Shahbaz et al., 2017; Afionis et al., 2017).

One of the prime reasons behind climate change, global warming, and environmental change is greenhouse gases (GHGs) emissions, with the carbon dioxide emissions being the most critical among all GHGs. It is worth noting that the share of CO_2 emissions in total GHGs comes as much high as 80% (Gill et al., 2018; Sarkodie and Strezov, 2019), implying that controlling CO_2 emissions is imperative in order to curb overall GHGs emissions. International organizations, with the support of developed and developing countries, have been trying to mitigate the levels of CO_2 emissions through several initiates (Kyoto protocol and Paris agreement); however, the levels of CO_2 emissions have been gradually rising across the globe. This concern calls for further actions, and especially propels to probe the key determinants of CO_2 emissions.

The literature on environmental economics reports that both economic growth and energy consumption are the prime reasons for high CO_2 emissions (Belke et al., 2011; Zhu et al., 2016). Economic growth, aided by non-renewable energy consumption, deteriorates the environmental quality (Zafar et al., 2020; Destek and Sinha, 2020; Mahalik et al., 2021). More specially, energy consumption exploits crude oil, coal, and natural gas' resources, which emit enormous CO_2

emissions. Likewise, economic growth allows consumers to consume pollution-intensive goods, which eventually lead to higher levels of CO_2 emissions. Hence, there exists an economy-environment dilemma, according to which, mitigating CO_2 emissions might affect economic growth. Therefore, it is imperative to explore other determinants of CO_2 emissions, so that they could be reduced without affecting economic growth.

The current literature put forwards several drivers of CO_2 emissions, such as financial development (Shahbaz et al., 2013a, b; Abbasi and Riaz, 2016; Dogan and Turkekul, 2016; Bekhet et al., 2017; Shoaib et al., 2020), trade (Halicioglu, 2009; Shahbaz et al., 2013a; Chen et al., 2019; Haug and Ucal, 2019), natural resources (Bekun et al., 2019; Danish et al., 2019; Khan et al., 2020), urbanization (Zhu et al., 2012; Sadorsky, 2014; Shahbaz et al., 2016; Ali et al., 2019), population (Dietz and Rosa, 1997; Begum et al., 2015; Dogan and Kan, 2018; Hashmi and Alam, 2019), energy prices (Zhang and Lin, 2012; Al-Mulali et al., 2013; Joo et al., 2015; Wang et al., 2016; Anser, 2019), energy efficiency (Khan et al., 2019; Nathaniel and Iheonu, 2019; Wolde and Weldemeskel, 2020), institutional quality (Abid, 2016; Bhattacharya et al., 2017), corruption (Sekrafi and Sghaier, 2018; Wang et al., 2018; Arminen and Menegaki, 2019), terrorism (Bildirici, 2020), globalization (Zaidi et al., 2019), and geopolitical risks (Adams et al., 2020). However, there exists a dearth of the literature on the nexus between unemployment and CO_2 emissions.

In addition, through the public and fiscal policy adjustment, such as the application of environmental taxes, has been found to potentially generate both environmental quality and employment or unemployment inferences. For instance, the double dividend hypothesis (DDH) though the application of environmental taxes, could improve or worsen environmental quality, while also increasing unemployment, depending on the understudied case (Carraro, et al., 1996; Degirmenci and Aydin, 2021). Accordingly, Schneider (1997) implies that the involuntary unemployment and environmental quality aspects of an ecological tax policy are presentable through the efficiency wage model. However, the dimension of unemployment-environment nexus, which has been sparsely presented in the literature, exhibits a close semblance or cut out from the aforementioned DDH. Illustratively, Forstater (2003) informs that full employment, along with desirable environment quality, is attainable through a public service employment program based on functional finance. In essence, attaining a trade-off relationship between unemployment and environmental degradation could essentially require special attention from various stakeholders (i.e., policy makers and government officials, among others). Thus, attaining a low unemployment rate without compromising the environment necessitates the implementation of desirable policies or reforms.

Recently, Kashem and Rahman (2020) put forward the Environmental Phillips Curve (EPC) hypothesis, according to which there exists a negative relationship between unemployment and environmental quality. Anser et al. (2021a) also report the validity of this hypothesis in the case of the BRICST countries. The proponents of EPC claim that high unemployment rates mitigate production and, hence, plunge CO_2 emissions. In contrast, increases in unemployment plunge consumers' income. As a result, the willingness to pay for improved environmental quality declines and, hence, carbon emissions are expected to increase. Furthermore, unemployment may increase or decrease environmental quality, and it is inevitable to empirically probe the unemployment-environment nexus to device policies for sustainable development.

Moreover, Kashem and Rahman (2020) employ economic growth and trade as determinants of carbon emissions, while modeling the unemployment-environment nexus. However, to prevent the empirical/econometric model from misspecification and to test the validity of this nexus in the presence of other key determinants, additional important variables (e.g., industrial production, energy consumption, and economic policy uncertainty) can be also incorporated. Recently, economic policy uncertainty (EPU) has emerged as one of the key influencing factors of environmental degradation (Jiang et al., 2019a). EPU has both economic and environmental effects, by altering the behavior of both consumers and producers, as well as that of environmental quality. Several studies have highlighted many channels capable of explaining the theoretical relationship between EPU and CO_2 emissions (Wang et al., 2020; Yu et al., 2021). In addition, a strand of the literature reports that EPU leads to higher CO_2 emissions (Danish et al., 2020; Anser et al., 2021b), whereas another group highlight that EPU impedes CO_2 emissions (Syed and Bouri, 2021; Yu et al., 2021). By contrast, a different strand of the empirical literature expounds the absence of any significant link between EPU and CO_2 emissions (Abbasi and Adedoyin, 2021). While devising policies related to the environmental impacts of EPU as implied above, the evidence has posited contrasting and inconsistent results. Hence, further investigation on the effect of EPU on the environment within the newly proposed EPC framework is needed to reshape the current policies on how to achieve sustainable development goals.

Based on the above milieu, the objective of this study is to scrutinize the validity of the EPC hypothesis, while probing the impact of EPU on CO_2 emissions in the US. The motivation to choose the US as the case study here is based on the fact that this country is the largest economy of the world, as well as the second largest carbon emitter on a worldwide basis. Additionally, the categorical components of EPU that include the fiscal, monetary, and trade policy were employed, while considering the test for the validity of the EPC hypothesis. It is worth mentioning that there exist a few limitations of the study by Kashem and Rahman (2020). First, their study uses static analysis and does not report the dynamic relationship between unemployment and environmental quality. Second, their study omits several key drivers of carbon emissions, such as uncertainty related to economic policies. In addition, US economic policies have turned to be substantially uncertain due to several external and internal issues (such as, the US-China trade war, the 2008 global financial crisis, and the twin deficit crisis). This study contributes to the literature in a sense that the findings are expected to help policy makers to devise reforms and policies to curb CO_2 emissions, which eventually lead to the achievement of sustainable development goals.

The contribution of this study to the existing literature is threefold: i) It explores the validity of the novel EPC hypothesis in the case of the US, ii) prior studies on the nexus of EPU and the environment considered only aggregate measures of economic policy uncertainty except for Alola (2019 a & b) that explored the only monetary uncertainty (MU) and trade uncertainty (TU) without the economic uncertainty. The economic intuition behind exploring the disaggregate EPU is that any shocks in EPU are in fact shocks in its components. Moreover, the recent changes in trade and economic policies of the United States arising from the country's foreign policy redirection especially with China and other major economies are enough reasons to consider the disaggregate EPU. Thus, it might be possible that the impact of these three types of uncertainty on CO_2 emissions is heterogeneous, in a sense that only one type of policy uncertainty surges CO_2 emissions, while the others plunge them. Therefore, we fill this line of research and examine the effect of MU, TU, and FU within the EPC framework, and iii) this study employs the novel methodology of dynamic ARDL simulations for robust and efficient findings. Compare to previous ARDL modelling methods (e.g., standard ARDL, bootstrap ARDL, NARDL, QARDL) this approach allows to graphically explore the effect of shocks in the regressors on the predicted value of the dependent variable, which can be useful for certain future policy actions. Furthermore, this approach renders reliable, efficient, and robust results even with small sample datasets, since this approach is a simulation-based algorithm.

Theoretical linkages

This section presents the theoretical linkage among the considered variables of this study. In particular, it proposes two channels that can theoretically connect unemployment with environmental quality. According to the 'growth channel', unemployment impedes economic growth, which on the other hand mitigates energy consumption. As a result, carbon emissions are expected to decrease. In contrast, the 'preference channel' argues that unemployment diminishes consumers' income, which does not allow individuals/households to express preferences in favor of improved environmental quality through expensive environmentally friendly goods.

On the other hand, there are several channels through which policy uncertainty affects CO_2 emissions. Jiang et al. (2019a) note that uncertainty about economic policy affects CO_2 emissions through the 'direct policy adjustment' effect, as well as the 'indirect economic demand' effect. The former illustrates that increased levels of EPU divert the attention of policymakers from environmental protection to economic stability, which renders opportunities for producers to use conventional (i.e., non-renewable energy) energy for production, thus, producing higher CO_2 emissions. The latter highlights that uncertainty regarding economic policy amends the decision-making process of economic agents, and thus, affects energy consumption, which eventually affects CO_2 emissions. In addition, Wang et al. (2020) put forward two other effects: i) the consumption effect, and ii) the investment effect. The former notes that EPU decreases the use of energy and pollution-intensive goods, which in turn leads to reduced CO_2 emissions. By contrast, the latter highlights that EPU has adverse effects on investments in R&D and renewable energy, which eventually upsurge CO_2 emissions.

Parallel to this, Yu et al. (2021) also propose three channels that bridge economic policies uncertainty with CO_2 emissions. These channels include: the innovations channel, the share of the fossil fuel energy channel, and the energy intensity channel. The first one supports that EPU leads to less innovations, and hence to higher CO_2 emissions. The second one explains that EPU increases the share of non-renewable energy in the energy mix, and thus, CO_2 emissions are expected to increase. Finally, the third channel expounds that EPU raises energy intensity, which escalates CO_2 emissions.

Literature review

This section is segmented into two subsections. The first one highlights the influencing factors of CO_2 emissions, while a number of studies on the nexus between EPU and CO_2 emissions are presented in the second part.

Determinants of CO_2 emissions

As climate change and global warming are increasing concerns across the world, a substantial number of researchers have analyzed them along with different influential factors impelling carbon emissions (Richmond and Kaufmann, 2006; Katircioğlu and Taşpinar, 2017; Mutascu, 2018; Jiang et al., 2019b). In the economy-environment nexus, the Environmental Kuznets Curve (EKC) hypothesis has been a prime conjecture (Dogan and Turkekul, 2016; Pata, 2018; Işık et al., 2019), which implies the presence of an inverted U-shaped relationship between income and environmental degradation. Researchers have been investigating the validity of the EKC hypothesis over the last decades and have generated mixed and contrasting results. One group report that an inverted U-shaped relationship between income and environment does exist (Tang and Tan, 2015; Bilgili et al., 2016; Kacprzyk and Kuchta, 2020), while the other group claim that the presence of a N-shaped relationship is valid (Lee and Oh, 2015; Allard et al., 2018). Several other studies expound the U-shaped and roughly M-shaped relationship between income and environment quality (Sinha et al., 2017; Minlah and Zhang, 2021). It is worth mentioning that models and methods, time period, countries, and the choice of control variables are mainly responsible for the mixed findings in the context of the EKC hypothesis (Heidari et al., 2015; Jamel and Maktouf, 2017; Pata, 2018).

Similarly, there are a few other studies that link (un)employment with the environment. More specifically, Witzke and Urfei (2001) examine the determinants of the willingness to pay for environmental issues, and they find the employment status is explicitly considered as one of those determinants. Likewise, Veisten et al. (2004) report that unemployment impedes the willingness to pay for high environmental quality. In contrast, there exists some empirical evidence which notes that the employment status and willingness to pay for environmental issues do not have any relationship between them (Torgler and García-Valiñas, 2007; Ferreira and Moro, 2013; De Silva and Pownall, 2014). Recently, Kashem and Rahman (2020) put forward the Environmental Phillips Curve (EPC) hypothesis, i.e., the presence of a negative relationship between unemployment and environmental quality. Additionally, Joshua and Alola (2020) examine the role of employment within the pollution haven hypothesis for the case of South Africa. They provide evidence that employment leads to high carbon emissions. Similarly, Gyamfi et al. (2020) use the EKC framework to investigate the relationship between employment and environment. The findings from this study document that rises in employment contribute to high carbon emissions. Next, Anser et al. (2021a) support the validity of EPC for the case of BRICST countries, and also report that economic growth and energy consumption escalate environmental degradation. In contrast, our study probes the impact of uncertainty related to economic policies within the EPC framework, whilst employing the novel dynamic ARDL simulations approach. In other words, our study extends the EPC literature in certain dimensions.

Parallel to this, energy consumption is often cited as one of the eminent drivers of CO_2 emissions (Saboori et al., 2014). The use of crude oil, natural gas, and coal emits high levels of CO_2 emissions (Destek and Sinha, 2020; Haug and Ucal, 2019). Several works also highlight the direction of causality between energy and environment (Zhang and Lin, 2012; Nathaniel and Iheonu, 2019). Moreover, one strand of the literature disaggregates energy into renewable and non-renewable energy and notes that these two energy sources have a heterogeneous impact on CO_2 emissions (Sadorsky, 2014). Likewise, energy efficiency (i.e., the productivity of energy consumption) plunges CO_2 emissions, since the same amount of energy can produce higher output (Afionis et al., 2017). Higher energy prices also can reduce the demand for energy, which eventually mitigates CO_2 emissions (Joo et al., 2014; Dogan and Turkekul, 2016).

Foreign direct investment (FDI) can either upsurge or impede CO_2 emissions. According to the pollution haven hypothesis, FDI could bring in environment unfriendly technologies. As a result, the levels of CO_2 emissions can significantly increase (Khavarian et al., 2019; Destek and Sinha, 2020). In contrast, the pollution Halo hypothesis notes that FDI encourages environment friendly technologies, and ultimately reduces CO_2 emissions (Belke et al., 2011; Jiang et al., 2019b). The environmental impact of trade is also unclear, because a strand of the literature argues that trade escalates environmental quality, while others reports that the opposite holds (Chen et al., 2019). More specifically, the trade-environment nexus depends on the nature of goods and services traded, as well as on the direction of trade (Halicioglu, 2009; Zhao et al., 2018).

Moreover, several studies report that natural resources also affect CO_2 emissions (Bekun et al., 2019; Danish et al., 2019). They note that urbanization escalates energy consumption, and hence, increases CO_2 emissions (Sadorsky, 2014; Ali et al., 2019). By contrast, others document that urbanization calls for improved environmental quality, which propels policy makers to initiate strict environmental measures, leading to reduced CO_2 emissions (Richmond and Kaufmann, 2006; Zhu et al., 2016; Bekhet et al., 2017). Likewise, tourism may also increase energy consumption due to the demand for infrastructure and transportation, which surges CO_2 emissions (Dietz and Rosa, 1997). Next, political, social, and economic globalization can also affect consumption and production decisions, and ultimately hit CO_2 emissions (Bilgili et al., 2016; Zaidi et al., 2019). The empirical literature also reports that political instability affects various economic decisions, and in turn, CO_2 emissions (Wang et al., 2018; Mahalik et al., 2021). Additionally, corruption, terrorism, and militarization can determine the levels of CO_2 emissions (Bildirici, 2020), while monetary, fiscal, and trade policies can also have direct, as well as indirect, impacts on CO_2 emissions (Halicioglu, 2009; Dogan and Turkekul, 2016). Finally, a few other research outlets also show that there exists an asymmetric impact of economic policies on CO_2 emissions (Danish et al., 2019).

The expansion of R&D investment, innovations, and technological advancements could improve energy efficiency, with these factors being able to put forward new methods to utilize renewable energy. As a result, CO_2 emissions are expected to get significantly plunged (Garrone and Grilli, 2010; Zhang and Zhang, 2018). Furthermore, financial development can also promote green investments, which reduce CO_2 emissions. By contrast, there exist a few empirical studies which report that financial development upsurges energy consumption and economic growth, therefore, escalating the levels of CO_2 emissions (Shahbaz et al., 2013a; Bekhet et al., 2017; Shoaib et al., 2020).

Economic policy uncertainty and environment

There are several studies that explore that relationship between EPU and the environment. EPU may disturb the decision making of economic agents, which affects CO_2 emissions (Jiang et al., 2019a). EPU can also affect CO_2 emissions through the energy efficiency channel (Danish et al., 2020). One strand of the literature on the EPU-environment nexus notes the positive relationship between EPU and the environment, while the other highlights the opposite. For instance, Adams et al. (2020) report that EPU escalates CO_2 emissions in the top resource rich economies. Similarly, Anser et al. (2021b) employ the STIRPAT model and note that EPU surges CO_2 emissions in the top ten carbon emitter countries. Likewise, using the world uncertainty index as a proxy for EPU, Wang et al. (2020) expound that EPU increases CO_2 emissions in the US. In addition, Adedoyin and Zakari (2020) employ the ARDL approach and corporate these findings in the case of the UK.

Syed and Bouri (2021) use the bootstrap ARDL approach and highlight that EPU reduces CO_2 emissions in the long run. Yu et al. (2021) describe that provincial EPU levels in China have an adverse impact on CO_2 emissions. Chen et al. (2021), however, document that EPU decreases CO_2 emissions in both the developed and developing countries, while Abbasi and Adedoyin (2021) use the dynamic ARDL approach and expound that EPU does not affect CO_2 emissions.

Based on the above discussion, it could be noted that the relationship between EPU and the environment is yet unclear. One of the reasons could be that instead of using disaggregate measures of EPU (i.e., MU, FU, and TU), the aggregate/composite measure has been extensively employed for the analysis in the prior literature. Although the study of Alola (2019 a & b) which is the closest considered the impact of the disaggregate parts of the EPU vis-à-vis the monetary and trade policy uncertainty on environmental degradation, the model is short of the economic and fiscal policy uncertainties. However, it might be possible that disaggregated policy uncertainty measures (i.e., MU, FU, and TU) have a heterogeneous impact on carbon emissions. Thus, it is inevitable to probe the disaggregated parts of EPU on carbon emissions.

The model

The empirical analysis has recently recommended an EPC framework, which expounds the presence of a negative relationship between unemployment and environmental quality (Kashem and Rahman, 2020; Anser et al., 2021a). Furthermore, it also augments EPC with the EKC framework proposed by Narayan and Narayan (2010). In their study, they present an EKC framework based on short- and long-run parameters. That is, if the value of the long-run coefficient of economic growth is lower than its short-run counterpart, then the EKC hypothesis does hold (Danish et al., 2020). Next, the analysis incorporates MU, FU, and TU into the modelling approach to examine whether these variables affect CO_2 emissions in the US. It also adds energy consumption as a control variable and the empirical model yields:

$$CO_2 = f(UNE, IPI, ENC, TU, MU, FU) \quad (1)$$

where, CO_2, UNE, IPI, ENC, TU, MU, and FU are CO_2 emissions, the unemployment rate, the industrial production index (a proxy of economic growth), energy consumption, trade policy uncertainty, monetary policy uncertainty, and fiscal policy uncertainty, respectively. The envisaged sign of UNE is expected to be negative, implying that higher unemployment mitigates the production of goods and services and, hence, impedes CO_2 emissions (Kashem and Rahman, 2020). IPI proxies economic growth, with the expected sign being positive, implying that industrial production upsurges carbon emissions (Syed and Bouri, 2021). Next, the expected sign of ENC is positive, which shows that increased consumption of fossil fuels deteriorates the environment by generating higher CO_2 emissions. The expected signs of TU, FU, and MU are positive, indicating that policy-related uncertainties escalate carbon emissions (Wang et al., 2020). However, there is weak empirical evidence for the presence of a negative relationship between policies-related uncertainty and environmental metrics (Syed and Bouri, 2021).

The ARDL methodology

The complex nature of economic indicators/variables allows them to behave differently in both the long- and short-run. That is, there is a likelihood of a positive relationship between variables in the long-run, while it is also possible that there exists a negative relationship between the same variables in the short-run. To cover this aspect, the ARDL approach has been extensively applied in the literature of economics and finance. More specifically, the ARDL model renders both the short- and long-run estimates and outperforms other co-integration methodologies for several reasons. For instance, the ARDL approach is functional if the variables are co-integrated at different orders. Moreover, it explicitly considers the issue of endogeneity, which may cause unreliable estimates. The ARDL modelling methodology also renders more reliable results even in the case of small samples, while it lets both the dependent and independent variables have different optimal lags, thus, providing relatively deep insights for policy implications. The equation for the ARDL model yields:

$$\Delta \mathrm{CO}_2 = \alpha + \sum_{i=1}^{p} \beta_i \Delta CO_{2_{t-i}} + \sum_{i=1}^{q} \gamma_i \Delta MU_{t-i} + \sum_{i=1}^{q} \omega_i \Delta FU_{t-i} + \sum_{i=1}^{q} \psi_i \Delta TU_{t-i} + \sum_{i=1}^{q} \delta_i \Delta IPI_{t-i} + \sum_{i=1}^{q} \varphi_i \Delta UNE_{t-i} + \sum_{i=1}^{q} \theta_i \Delta ENC_{t-i} + \pi_1 CO_{2_{t-1}} + \pi_2 MU_{t-1} + \pi_3 FU_{t-1} + \pi_4 IPI_{t-1} + \pi_5 UNE_{t-1} + \pi_6 ENC_{t-1} + \varepsilon_t \quad (2)$$

where GDP shows GDP per capita, GDP2 represents the squared GDP, and ENC represents energy consumption, respectively. Δ denotes first differences, i represents time lag, t denotes time, and ε_t is the error term. In addition, π_i (i = 1, …, 6) shows long-run elasticity, with β, γ, ω, ψ, δ, φ, and θ being short-run parameters.

The envisaged signs of GDP and GDP2 are positive and negative, respectively. This shows that EKC does exist (Syed and Bouri, 2021). In addition, the expected coefficient of ENC is positive, implying that energy consumption leads to higher CO_2 emissions (Anser et al., 2021b). Yet, the expected signs of MU, FU, and TU remain unknown.

The dynamic ARDL simulations approach

Although the ARDL approach renders both short- and long-run estimates, the complex dynamic nature of ARDL modeling causes a few inconveniences, while explaining and/or interpreting the coefficients. Moreover, the inclusion of multiple lags, differences, and lag differences may cause complexities in the ARDL approach (Jordan and Philips, 2018). To overcome these issues, Jordan and Philips (2018) put forward the dynamic ARDL simulations approach. This method uses simulations to render more robust and efficient outcomes. In addition, this novel approach allows investigating the effect of positive and negative shocks in the independent variables on the dependent variable through dynamic plots. The dynamic ARDL approach often uses 5,000 simulations, and, hence, the analysis also applies the same number. Furthermore, the analysis selects the optimal number lags on the basis of the AIC criterion. Additionally, to check the overall performance of the model, the analysis employs several diagnostic tests, i.e., the Breusch-Godfrey Lagrange multiplier (LM) test, the Breusch-Pagan-Godfrey (BG) test, and the Jarque-Bera test. The error correction form of the dynamic ARDL model yields Equation (3) below:

$$\Delta \mathrm{CO}_2 = \alpha + \sum_{i=1}^{p} \beta_i \Delta CO_{2_{t-i}} + \sum_{i=1}^{q} \gamma_i \Delta MU_{t-i} + \sum_{i=1}^{q} \omega_i \Delta FU_{t-i} + \sum_{i=1}^{q} \psi_i \Delta TU_{t-i} + \sum_{i=1}^{q} \delta_i \Delta IPI_{t-i} + \sum_{i=1}^{q} \varphi_i \Delta UNE_{t-i} + \sum_{i=1}^{q} \theta_i \Delta ENC_{t-i} + \pi_1 CO_{2_{t-1}} + \pi_2 MU_{t-1} + \pi_3 FU_{t-1} + \pi_4 IPI_{t-1} + \pi_5 UNE_{t-1} + \pi_6 ENC_{t-1} + \varepsilon_t \quad (3)$$

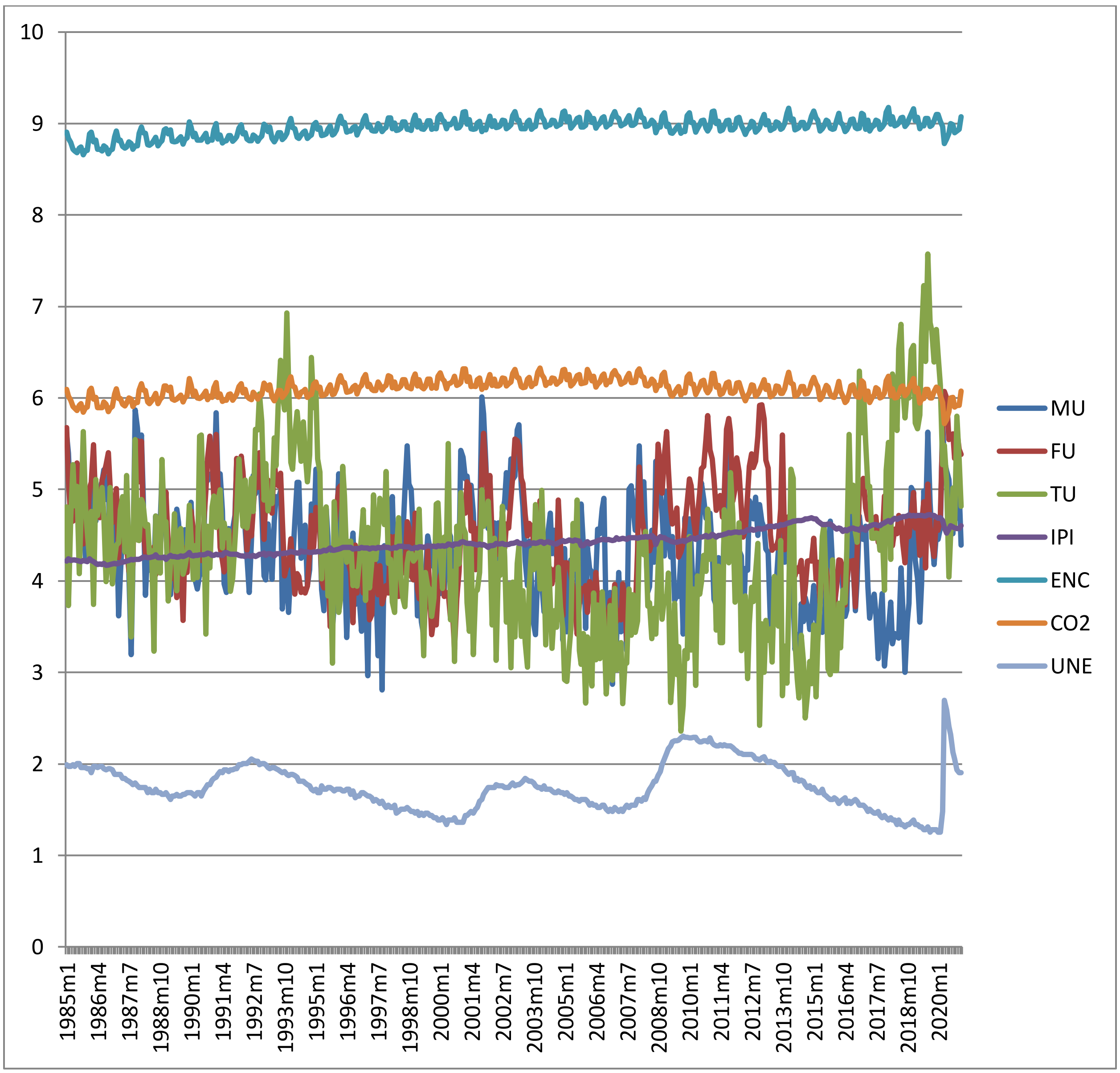
It is worth mentioning that both Equation (2) and (3) are similar and they are presented in a standard format; however, the approach to estimate them is quite different.

Data

The objective of this study is to probe the validity of the EPC hypothesis, along with the role of MU, FU, and TU in the case of the US. Hence, to this end, the analysis makes use of monthly data, spanning the period 1985 to 2018. CO_2 emissions are measured in metric tons, while industrial production is measured with respect to 2012 as the base year, and energy consumption is measured in oil equivalent per capita. IPI is used as a proxy for GDP, since monthly data of GDP are not available. Syed and Bouri (2021) also employ IPI as a proxy for GDP and examine the validity of the EKC hypothesis.

Next, the key independent variables are the unemployment rate (% of the labor force), the monetary policy uncertainty index, the trade policy uncertainty index, and the fiscal policy uncertainty index. Monetary policy uncertainty is fluctuations and ambiguity about monetary policy, especially the ambiguity related to interest rates set by the central bank (the Fed). Similarly, fiscal policy uncertainty is the uncertainty about tax reforms and government expenditures. Likewise, trade policy uncertainty is the fluctuations and/or uncertainty related to tariff and non-tariff barriers, the uncertainty about trade agreements, trade remedy laws, and exchange rate management. Data on the unemployment rate, energy consumption, carbon emissions, and industrial production are retrieved from the Federal Reserve Economic Database (FRED) and the Energy Information Administration (EIA). Data on MU, FU, and TU are obtained from policyuncertainty.com. It is worth mentioning that MU, FU, and TU are calculated on the basis of methodology developed by Baker et al. (2016). That is, Baker et al. (2016) calculate policy uncertainty about several economic policies through newspaper articles. For instance, MU is calculated through the frequency of the number of related words (e.g., monetary policy, uncertainty, interest rate uncertainty, among others) in newspaper articles. The same method is used to calculate FU and TU. Next, the trend of selected variables of this study is depicted in Figure 1.

Figure 1: Historical trend of selected variables



As can be seen from Figure 1, there exists relatively high uncertainty in MU, FU, and TU as compare to other variables such as IPI and carbon emissions.

The summary of data is reported in Table 1, while summary statistics are reported in Table 2. All series are expressed in logs to provide a better interpretation of the estimates, as well as to avoid heteroscedasticity issues.

Table 1 Data source and variables

Symbol	**Indicator**	**Measurement**	**Source**
CO_2	Carbon dioxide emissions	Metric ton	EIA
IPI	Industrial production index	Level of production against the base tear 2012	FRED
ENC	Energy consumption	Oil equivalent per capita	EIA
UNE	Unemployment rate	Percentage of labor force	FRED
MU	Monetary policy uncertainty index	Frequency of "monetary policy uncertainty" related words in newspaper articles	Policyuncertainty.com
FU	Fiscal policy uncertainty index	Frequency of "fiscal policy uncertainty" related words in newspaper articles	Policyuncertainty.com
TU	Trade policy uncertainty index	Frequency of "trade policy uncertainty" related words in newspaper articles	Policyuncertainty.com

EIA is Energy Information Administration, whereas FRED is Federal Reserve Economic Database.

Table 2 Descriptive statistics

	MU	FU	CO_2	IPI	UNE	TU	ENC
Mean	4.36	4.51	6.09	4.42	1.75	4.35	8.95
Median	4.04	4.21	6.02	4.13	1/20	4.08	8.08
Std. Dev.	0.59	0.56	0.10	0.14	0.25	0.93	0.10
Skewness	0.72	0.01	0.03	0.00	0.00	0.00	0.00
Kurtosis	0.07	0.02	0.59	0.00	0.74	0.31	0.70
Jarque-Bera	(0.19)	(0.00)***	(0.09)*	(0.00)***	(0.00)***	(0.00)***	(0.00)***

*, ** and *** shows level of significance at 10%, 5% and 1% respectively. (.) indicates probability value.

As can be seen from Table 2, TU shows the standard deviation (i.e., 0.93) across the uncertainty variables, implying that TU is the most volatile series. In contrast, the standard deviation for CO_2 emissions and ENC is the lowest, implying that both of them do not drastically fluctuate over time. Additionally, all series are positively skewed and do not contain heavy tails. It is worth reporting that all series are non-normally distributed except MU, which follows a normal distribution.

Next, the Elliot et al. (1996) unit root test has been employed and the findings are reported in Table 3. The findings clearly document the presence of a unit root in the levels of all variables under study, while they turn stationary in their first differences, rendering support for the employment of the ARDL modelling approach.

Table 3 GLS-ADF unit root test

	t-statistics	
Variables	**I(0)**	**I(1)**
CO_2	-1.28	-4.34***
MU	-2.11	-3.14***
FU	-1.35	-4.26***
TU	-2.41	-5.02***
IPI	-2.05	-4.98***
ENC	-0.12	-4.21***
UNE	-1.89	-2.87**

*, **, *** denotes level of significance at 1%, 5%, and 10%, respectively.

Empirical results

The Bounds test

First, Table 4 presents the findings from the bounds test. As can be seen, the estimated values from both the F- and t-statistics are greater than the upper bounds values, clearly indicating that there exists co-integration among the variables under consideration.

Table 4 Bounds test

Test Statistic	Value	I (0)	I (1)
F-statistic	3.64	2.02	3.24
t-statistic	-4.45	-1.95	-4.04

Lower and upper bound values are given at 5%.

ARDL results

Next, we report short- and long-run coefficients from the ARDL model in Table 5. The short-run coefficients (Panel I) of MU, TU, and FU are statistically insignificant, implying that monetary, fiscal, and trade policy uncertainty do not affect carbon emissions. The findings are in line with the conclusion provided by Abbasi and Addedoyin (2021) who note that economic policy uncertainty does not lead to higher carbon emissions. The reason could be the same magnitude of the channels/effects that affect carbon emissions. For instance, if the magnitude of the investment effect is almost equal to the consumption effect, the net effect of policy uncertainty on carbon emissions is zero. Next, the coefficient of UNE is -0.02 and it is statistically significant, indicating that a 1% increase in the unemployment rate plunges carbon emissions by 0.02%. That is, a 1% increase in the unemployment rate plunges carbon emissions about by 1588 metric tons. The reason for this observation is that increases in unemployment plunges production and, hence, carbon emissions are expected to decrease. Hence, we report the validity of EPC in the short run for the case of the US. This finding is also backed by the conclusions reached by Anser et al. (2021a). Moreover, the coefficients of industrial production and ENC turn out to be 0.17 and 0.98, respectively, indicating that both upsurge carbon emissions.

Table 5 ARDL estimates

Indicator	Value	Probability Value
Short-run estimates (Panel I)		
ΔMU_t	0.00	0.10
ΔFU_t	-0.00	0.10
ΔIPI_t	0.17	0.00***
ΔUNE_t	-0.02	0.00***
ΔTU_t	0.11	0.20
ΔENC_t	0.98	0.00***
ΔENC_{t-1}	-0.26	0.11
Long-run estimates (Panel II)		
CO_{2t-1}	-0.45	0.10
MU_{t-1}	0.05	0.02***
FU_{t-1}	-0.06	0.02***
TU_{t-1}	-0.02	0.03**
IPI_{t-1}	-0.24	0.00***
UNE_{t-1}	-0.01	0.11
ENC_{t-1}	0.81	0.00***
Diagnostics (Panel III)		
R^2 (Adjusted)		0.79
Ramsey RESET test		(0.57)
LM test		(0.21)
CUSUM test		Stable
$CUSUM^2$ test		Stable
Jarque-Bera test		(0.27)

ARCH test	(0.79)
ECT	-0.04***

*, **, *** denotes level of significance at 1%, 5%, and 10%, respectively.

Regarding the long-run estimates (Panel II), the coefficient of MU is positive and statistically significant. The value of MU is 0.05, implying that a 1% increase in monetary policy uncertainty escalates carbon emissions by 0.05%. That is, a 1% increase in MU escalates carbon emissions by approximately 615 metric tons. This result is in line with those by Danish et al. (2020), who report that the EPU index escalates carbon emissions. Similarly, the coefficient of FU is negative (i.e., -0.06) and statistically significant, indicating that a 1% increase in fiscal policy uncertainty plunges carbon emissions by 0.06%. In particular, a 1% upsurge in FU plunges the carbon emissions by approximately 738 metric tons. This outcome is backed by the results of Yu et al. (2021), who note that provincial levels of EPU mitigate carbon emissions. In addition, the coefficient of TU is negative (i.e., -0.02) and statistically significant, displaying that plunge in carbon emissions by 0.02% is fostered by a 1% increase in trade policy uncertainty. This implies that a 1% increase in TU impedes carbon emissions by approximately 246 metric tons. This conclusion is in line with the findings by Chen et al. (2021), with their studies using aggregate measures of economic policy uncertainty, while ours use disaggregated measures. The long-run coefficient of industrial production is negative and statistically significant. Since the short- and long-run coefficients of IPI are respectively positive and negative, we report that EKC does not hold. Furthermore, the coefficient of ENC is positive and statistically significant, noting that energy consumption leads to higher carbon emissions.

Next, in Panel III (Table 5) we report several diagnostics of the ARDL model for reliability and robustness purposes. In order to probe the model's misspecification, the analysis applies the Ramsey's RESET test. Its value is 0.57, indicating that the model is well specified. Next, it employs the LM serial correlation test to discern whether there exists serial correlation between the errors. Its value is 0.21, implying that the errors are not correlated. The CUSUM and CUSUM-square tests also explore the stability of the model. Their graphical representations are reported in Figures 2.1 and 2.2. As can be seen from both tests, the blue line lie within the critical bounds (red lines), thus, we can safely conclude that the exhibits satisfactory stability. The ARCH test, which shows heteroscedasticity, notes that the errors variance is constant, indicating that the model does not suffer from heteroscedasticity. Finally, the ECT (error correction term) is -0.04, which is statistically significant, with its value expounding that any shock to the long-run equilibrium is corrected by 4% each month.

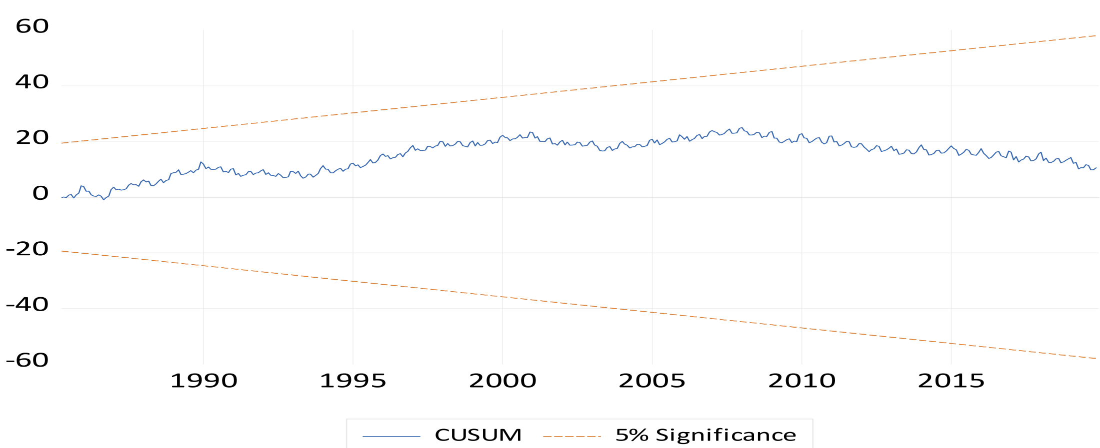


Fig. 2.1 CUSUM test

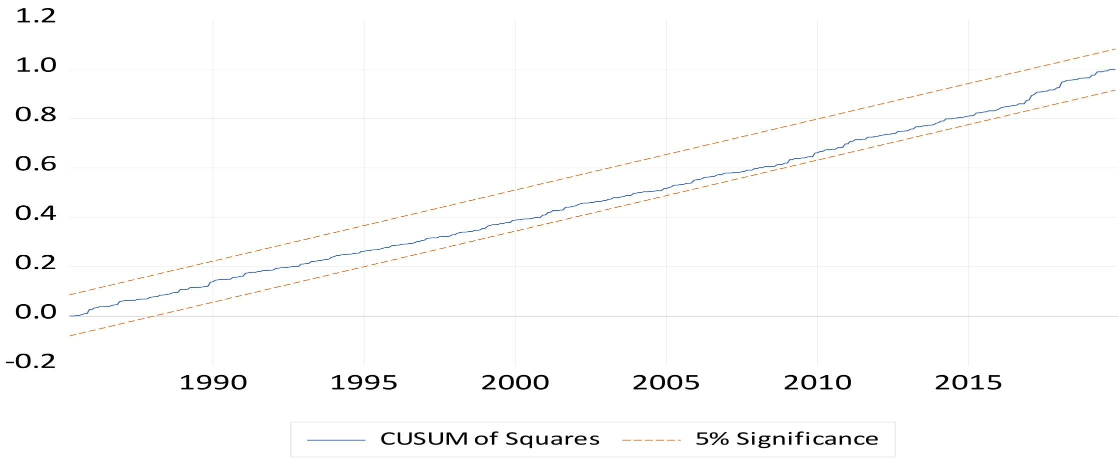


Fig. 2.2 CUSUM-square test

The dynamic ARDL findings

This section presents the results from the novel dynamic ARDL approach, with the optimal lags being selected through the AIC. The short- and long-run estimates are reported in Table 6. Panel I presents the short-run estimates. More specifically, the coefficient of MU is 0.002 and it is statistically significant, implying that a 1% surge in monetary policy uncertainty escalates carbon emissions by 0.002%. This reports that a 1% increase in MU surges emissions by 246 metric tons. This finding is in line with the conclusions of Amin and Dogan (2021) who highlight that aggregate measures of policy uncertainty (i.e., economic policy uncertainty-EPU) upsurge carbon emissions. The reason might be the fact that monetary policy uncertainty plunges investments in clean energy, R&D, and technology advancements which in turn upsurge carbon emissions. Furthermore, the cumulative magnitude of the investment effect, the innovation channel, the share of the fossil fuel channel, and the energy intensity channel is higher than the combine magnitude of those channels that impedes carbon emissions. In contrast, the coefficient of FU is negative and statistically significant. In particular, the coefficient of FU expounds that a 1% increase in fiscal policy uncertainty plunges emissions by 0.003%. That is, carbon emissions decrease by almost 36 metric tons due to a 1% increase in FU. This outcome is similar to the conclusion of Syed and Bouri (2021) and Chen et al. (2021). Overall, we can conclude that the magnitude of the consumption effect is higher than all those channels that escalate emissions. The potential reason for this finding could be that fiscal policy uncertainty may plummet energy consumption and economic growth and hence emissions are expected to decrease. Next, the coefficient of TU is statistically insignificant, indicating that trade policy uncertainty does not affect carbon emissions. This finding is somehow similar to the results of Abbasi and Addedoyin (2021), who report that policy uncertainty does not affect emissions. Furthermore, the coefficient of UNE is statistically insignificant, which indicates that unemployment does not affect the environment, thus providing evidence that EPC does not hold in the short run. Next, the coefficient of IPI and ENC are negative and positive, respectively. This highlights that industrial production plunges emissions, while energy consumption escalates them.

Regarding the long-run estimates (Panel II), the coefficients of MU and FU are 0.002 and -0.002, respectively, indicating that MU escalates carbon emissions, whereas FU plunges them. In contrast, the coefficient of TU is statistically insignificant, implying that trade policy uncertainty does not alter these emissions. It is worth mentioning that both the short- and long-run results for MU, FU, and TU are almost similar. The value of UNE is -0.023 and it is statistically significant, indicating that a 1% increase in unemployment plunges emissions by 0.023%. That is, a 1% increase in unemployment rate surges the emissions by 282 metric tons. This outcome complements the conclusion of Kashem and Rahman (2020) and Anser et al. (2021a). In fact, the rise in the unemployment rate plunges both production and energy consumption. As a result, carbon emissions are expected to be deceased. By contrast, both IPI and ENC escalate emissions in long run. Short- and long-run coefficients of IPI are negative and positive, respectively, which invalidates the validity of EKC in the case of the US.

Related to the diagnostic tests, ECT is -0.07 and statistically significant, highlighting that a shock makes carbon emissions to converge by 7% each month. The probability value of the model's F-statistic is also statistically significant, while both the CUSUM and CUSUM-square tests expound that model is stable. Moreover, we plot the impact of a shock in the independent variables on the dependent variable through a dynamic ARDL simulations approach. We set 5,000 simulations as default and we examine the positive and negative shocks of 10% in the independent variables.

Table 6 Dynamic ARDL estimates

Indicator	Coefficient	p-value
Short-run estimates (Panel I)		
ΔMU_t	0.002	0.00***
ΔFU_t	-0.003	0.00***
ΔIPI_t	-0.021	0.00***
ΔUNE_t	0.009	0.20
ΔTU_t	-0.001	0.16
ΔENC_t	0.070	0.00***
$\Delta CO_{2\ t}$	-0.260	0.00***
Long-run estimates (Panel II)		
MU_{t-1}	0.002	0.02**
FU_{t-1}	-0.002	0.02**
TU_{t-1}	-0.002	0.13

IPI_{t-1}	0.151	0.00***
UNE_{t-1}	-0.023	0.00***
ENC_{t-1}	1.023	0.00***
Diagnostics (Panel III)		
R^2 (Adjusted)		0.80
p-value of F-statistic		(0.00)***
Simulations		5000
CUSUM test		Stable
$CUSUM^2$ test		Stable
ECT		-0.07***

*, **, *** denotes level of significance at 1%, 5%, and 10%, respectively. (.) reports p-value

Figures 3 and 4 illustrate that a shock of +10% in MU escalates carbon emissions in both the short and long run. In addition, a shock of -10% in MU plunges emissions in both the short and long run. Furthermore, Figures 5 and 6 expound the shock in FU, and its impact on the predicted value of carbon emissions. A positive shock in FU impedes emissions in the short, as well as the long run. In contrast, a negative shock in FU surges emissions in both the short and long run.

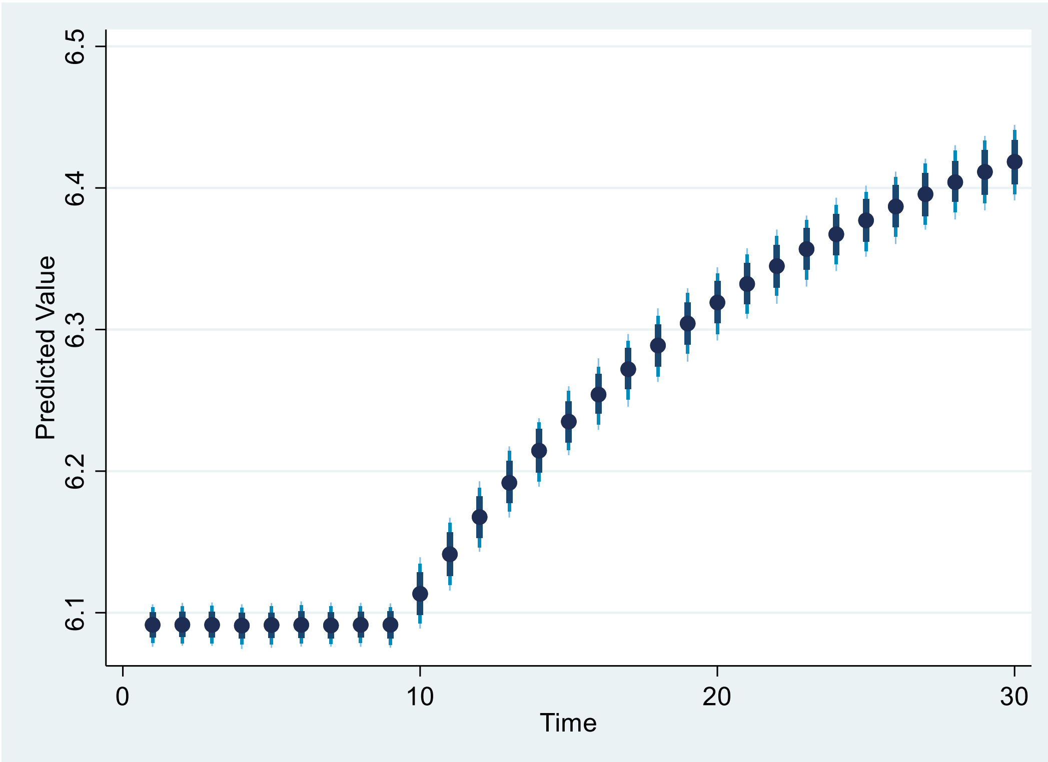


Fig. 3. +10% shock in monetary policy uncertainty

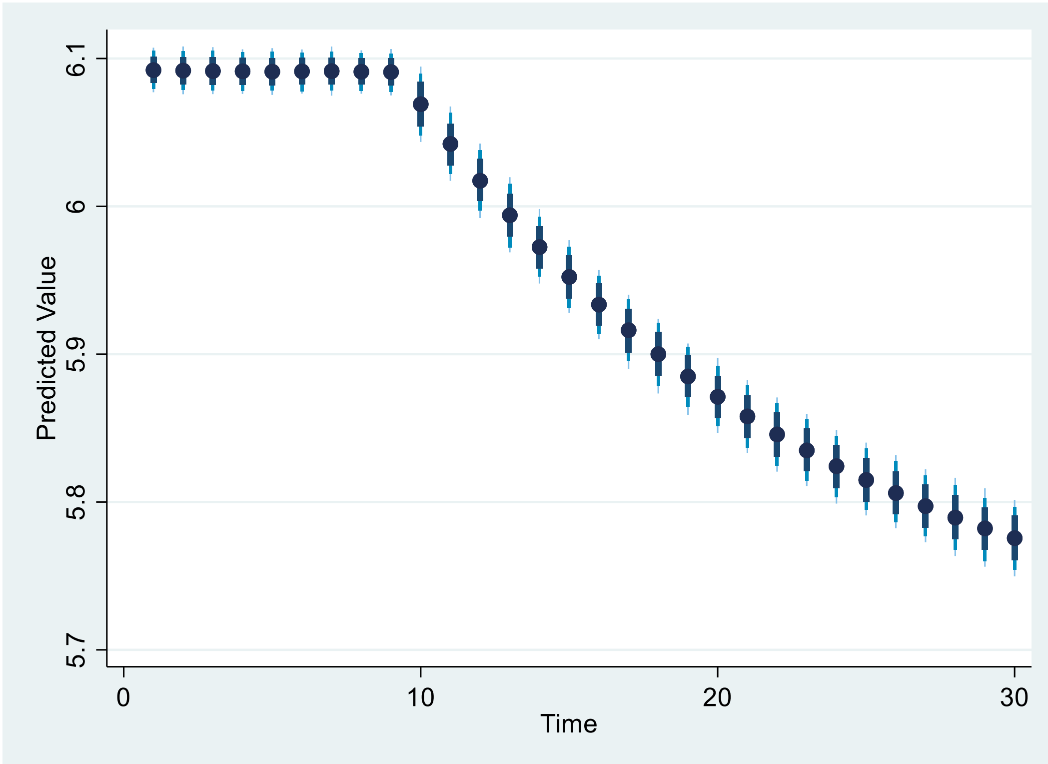


Fig. 4. A shock of -10% in monetary policy uncertainty

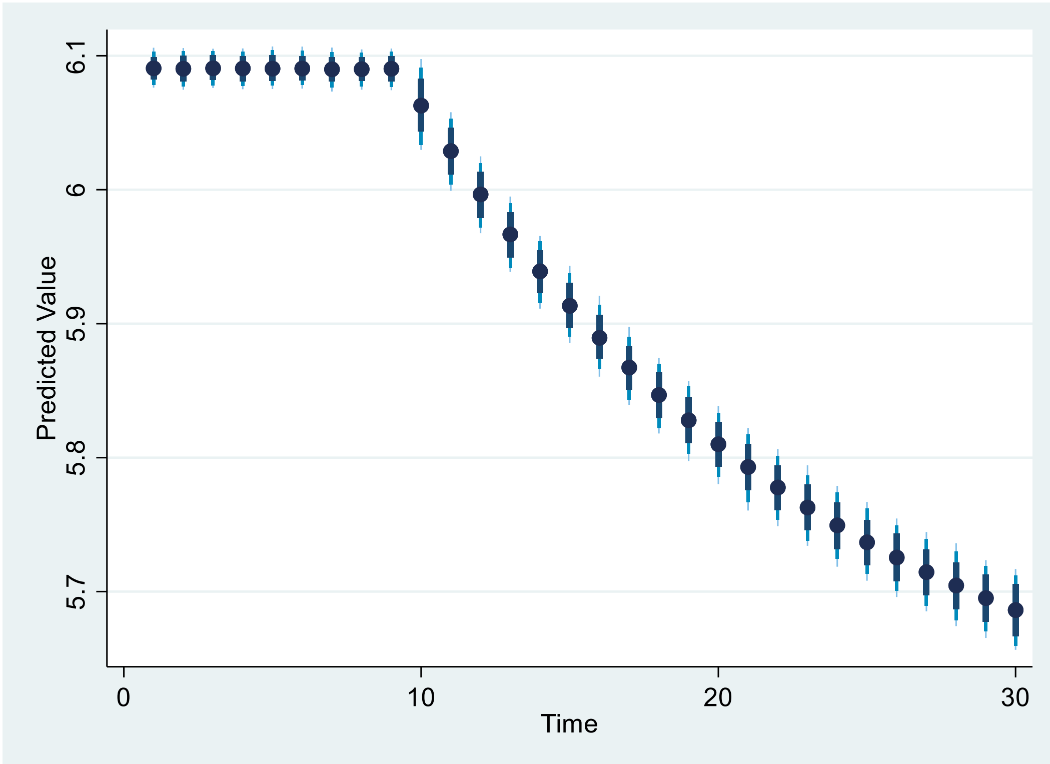


Fig. 5. A shock of +10% in fiscal policy uncertainty

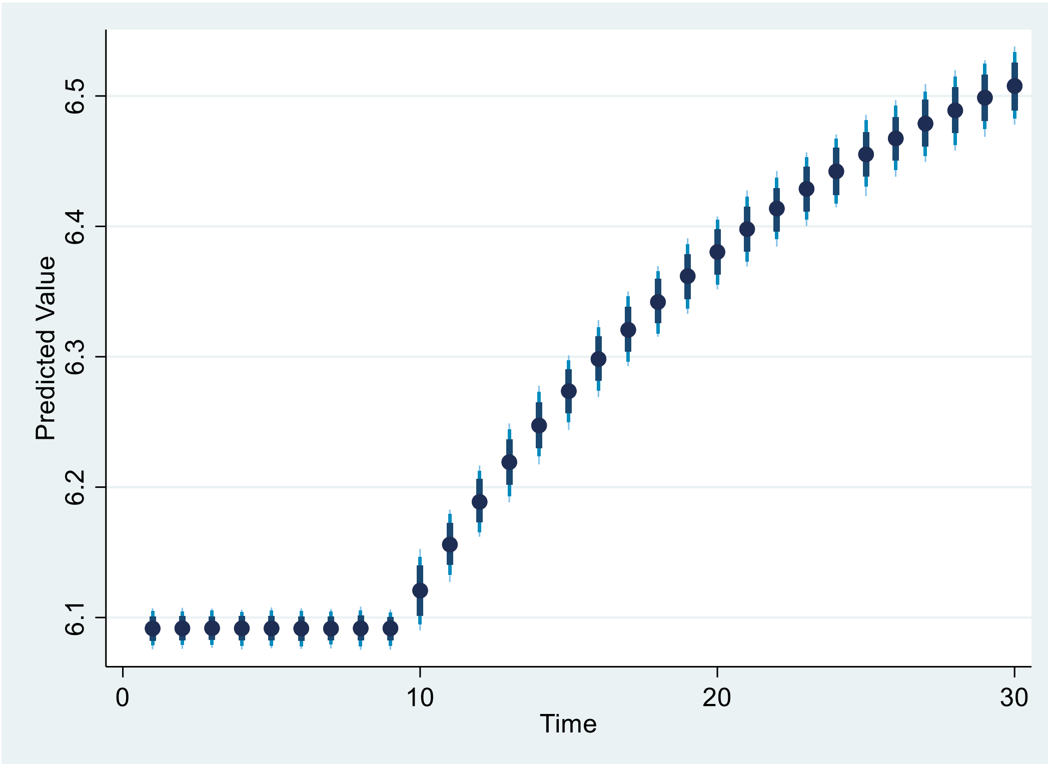


Fig. 6. A shock of -10% in fiscal policy uncertainty

Similarly, as can be seen from Figures 7 and 8, a shock in trade policy uncertainty does not affect the predicted value of carbon emissions, while Figure 9 depicts that a positive 10% shock in unemployment slightly increases emissions in the short run, while it plunges them in the long run. In contrast, Figure 10 highlights that a negative shock in unemployment plunges emissions in the short run, while it escalates them in the long run.

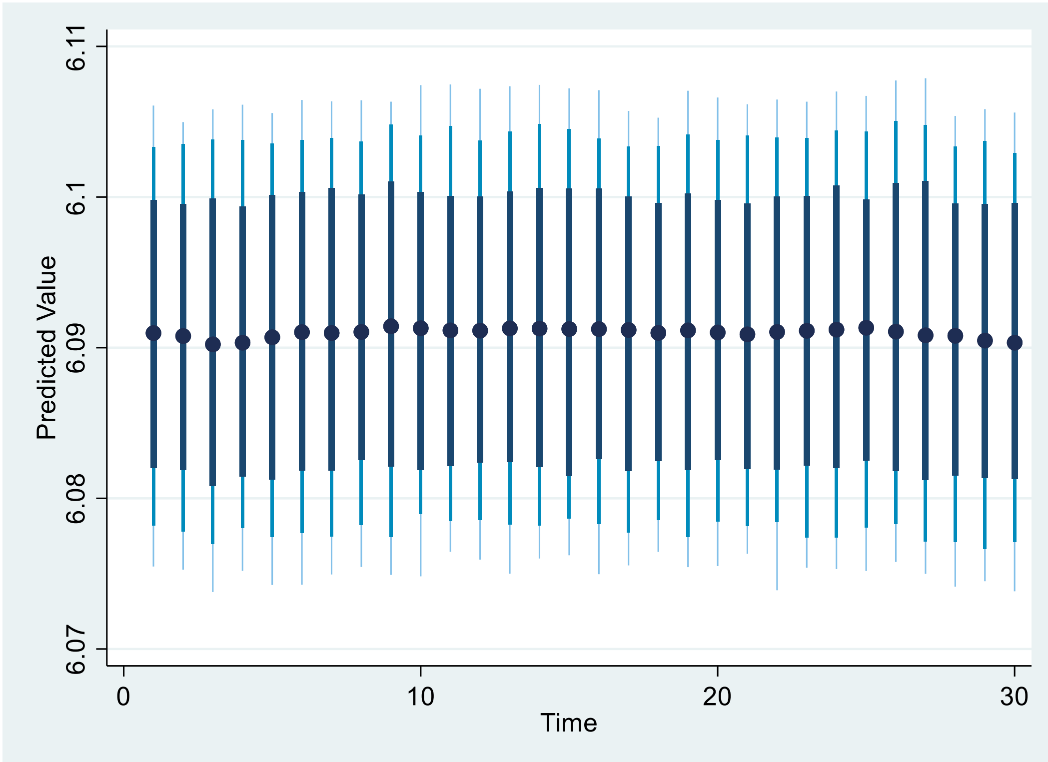


Fig. 7. A +10% shock in trade policy uncertainty

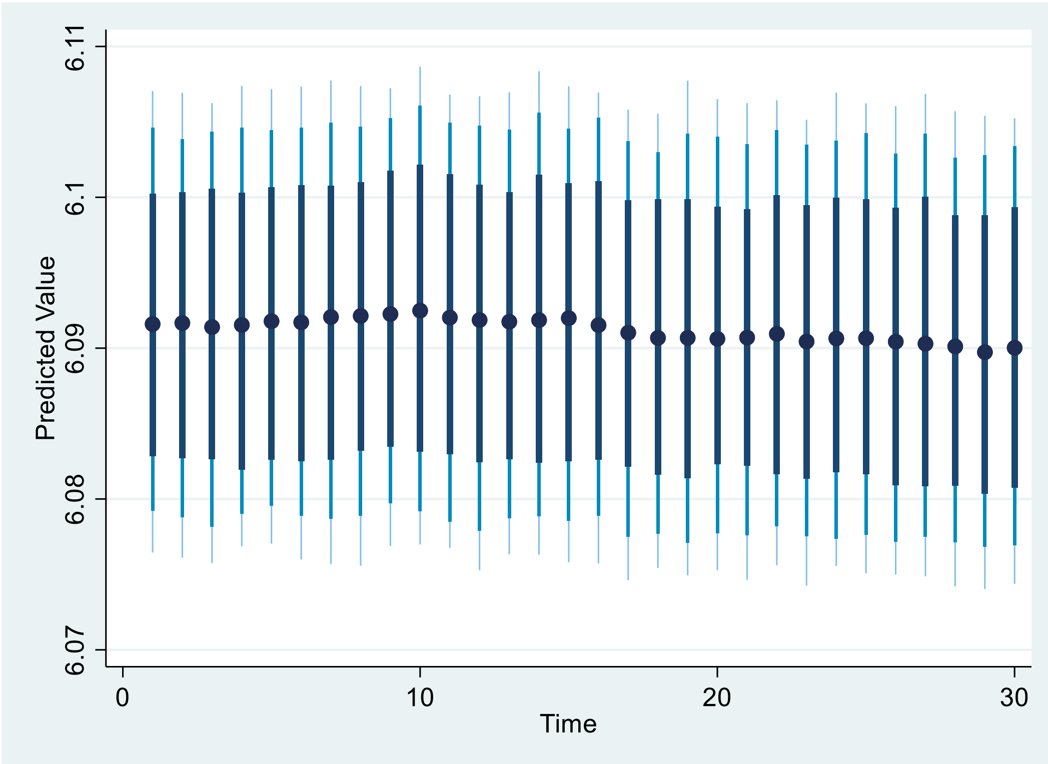


Fig. 8. A -10% shock in trade policy uncertainty

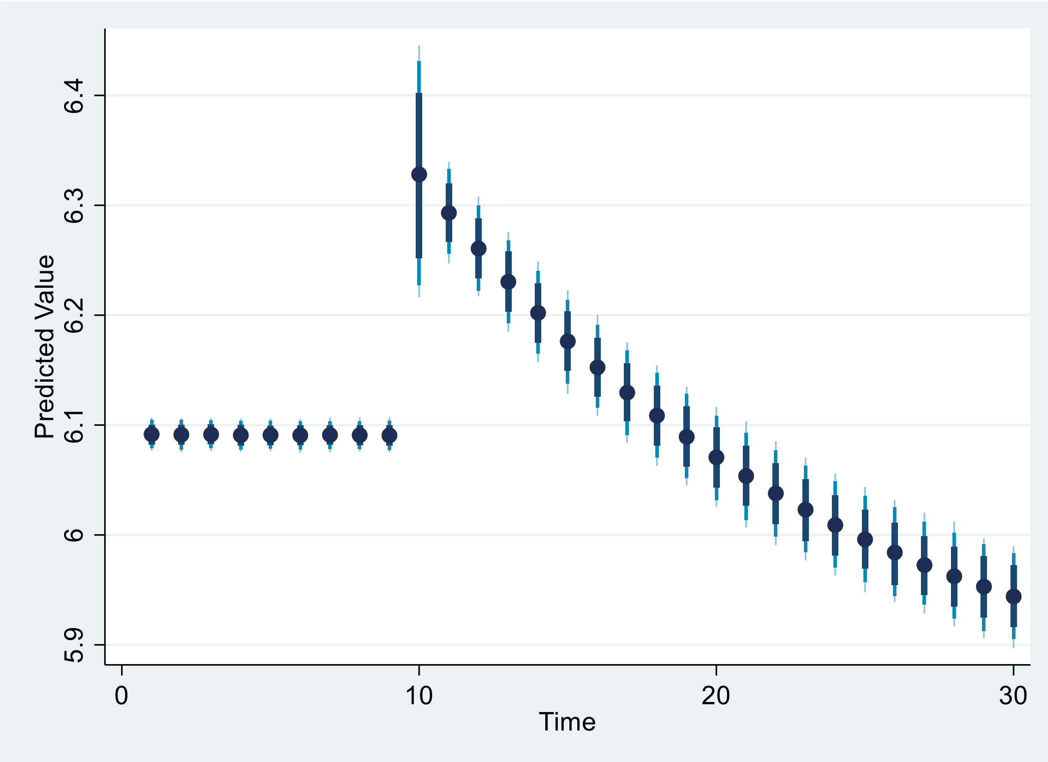


Fig. 9. A shock of +10% in unemployment

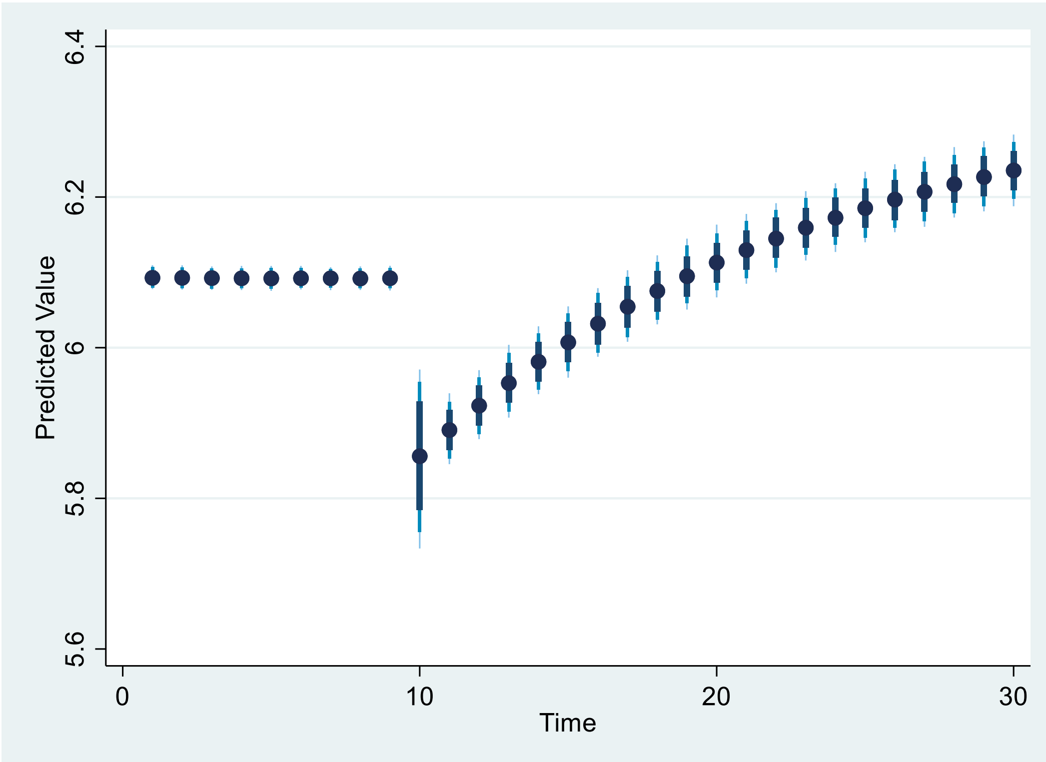


Fig. 10. A shock of -10% in unemployment

The summary of results is reported in Table 7. As can be seen that EPC is found to be valid in the long-run, however, it does not exist in the short-run. Moreover, MU and FU respectively increase and decreases carbon emissions in both the short- and long-run. Interestingly, TU affects carbon emissions neither in the short- nor in the long-run. Finally, IPI escalates the emissions only in the long-run.

Table 7 Summary of Findings from dynamic ARDL simulations

Variable	Short-run	Long-run
IPI	Negative	Positive
ENC	Positive	Positive
UNE	No relationship	Negative

MU	Positive	Positive
FU	Negative	Negative
TU	No relationship	No relationship

Conclusion

The goal of this study was to probe the validity of the Environmental Phillips Curve (EPC) in the US to investigate the impact of monetary policy uncertainty (MU), trade policy uncertainty (TU), and fiscal policy uncertainty (FU) on carbon dioxide emissions. To this end, the analysis employed the novel methodology of dynamic ARDL simulations. The findings showed that EPC did not hold in the short run; however, there its validity was confirmed in the long run. Furthermore, MU escalated emissions in both the short and long run. In contrast, FU mitigated emissions in the short run, as well as in the long run. In addition, TU did not affect carbon emissions either in the short or in the long run. The result of the impact negative impact of FU on environment degradation could largely be related with the executive decisions vis-à-vis political party partisanship on issues of energy and climate change. Moreover, the monetary policy which is at the control of the Federal Reserves are sure determinants of economic productivity, giving the sensitivity of the United States economy to interest rates and other monetary policy drivers.

The study also deduces certain policy implications. Given that decreases in unemployment lead to escalated emissions, policymakers should further expand innovative policy measures such as energy efficiency and environmental technologies (e.g., renewable energy, innovations, and clean technologies that include carbon sequestration and storage) that expectedly spur economic productivity in order to substantially mitigate the level of emissions without any detrimental effects on unemployment. With such policy, economic stakeholders could be encouraged through subsidies and tax waiver/reduction on energy-related importations and investments in energy technologies that are harmless to the environment while also creating sustainable employment and entrepreneurial opportunities. Concerning the role of various forms of economic uncertainty, particularly in relevance to those that exerts a negative impact on carbon emissions, the derived findings also suggest that policymakers (i.e., monetary authorities/central banks) should strive to maintain the continuity and stability of such desirable policies in order minimize their negative impact both on carbon emissions and on unemployment. To a large extent, undesirable results are better avoided through the optimization of sustainable energy consumption structure and the adoption of emission reduction strategies from various sources. When economies face increasing economic policy uncertainty, they opt to use cheaper and dirtier fossil fuels, and this leads to increased carbon emission intensities, along with the associated negative repercussions to the unemployment rate. Overall, policymakers must pay close attention to the impact of policy uncertainties on their credibility when formulating and changing their policies.

Author contribution

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Funding: Not applicable

Data availability: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval: Not applicable.

Consent to participate: Not applicable.

Consent to publish: Not applicable.

Competing interests: The authors declare no competing interests.

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