Original Article

Testing the pollution haven hypothesis on the pathway of sustainable development: Accounting the role of nuclear energy consumption

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ABSTRACT

The environmental effects of China's nuclear energy consumption in a dynamic framework of the pollution haven hypothesis are examined. This study uses a dynamic autoregressive distributed lag simulation approach. Empirical evidence confirms that the pollution haven hypothesis does not exist for China; i.e., foreign direct investment plays a promising role in influencing environmental outcomes. Furthermore, empirical results concluded positive contribution of nuclear energy in pollution mitigation. From the results it is expected that encouraging foreign investment to increase generation of nuclear energy would benefit environmental quality by reducing CO_2 emissions.

1. Introduction

China is among the most polluted countries globally, facing the challenge of rising carbon emissions. For the country's sustainable growth, it is imperative to identify possible factors to mitigate pollution [1]. Foreign direct investment (FDI) inflow is among key elements that boost economic growth worldwide as the process of financial liberalization and the integration of global economies has increased over the last three decades [2]. Initially, several studies have focused on validating the "Pollution Haven Hypothesis" (PHH) and the "Porter Hypothesis" while investigating the linkage between FDI and CO_2 emissions. The former states that developed countries shift their polluting industries to developing countries with lower prices of inputs (labor wages and low energy cost) [3]. FDI may include the transfer of technology from the source country to the host country, leading to greater investment in clean energy [4]. China is among the world's largest FDI recipients [5], and with reform in the economic sector, China has countersigned a remarkable FDI inflow [5] where FDI has risen from $3.5 billion to $121 billion from 1990 to 2012 [6]. The growth of carbon emissions in China is sequentially becoming a burden to environmental sustainability, which needs full consideration. The inclining use of fossil fuels for industrialization is the underlying cause of China's failure to meet its mitigation target [7]. Fossil energy contributes to CO_2 emission [8] and a large number of fossil fuel consumption leads to environmental degradation [9], which remains a huge obstacle to sustainable development [10].

Because of the rising environmental and health consequences of CO_2 emissions, a transition toward the adoption of clean energy sources (nuclear, hydro, and solar) is critical for electricity generation to reduce greenhouse gas (GHG) emissions [11]. Global warming is a cause of climate change, and scholars are concerned about switching from dirty energy sources toward clean sources [12]. Nuclear energy has been acknowledged as a potential source of emission mitigation [13]. Renewable energy is comparatively more profitable with great market potential. The development of renewables stimulates economic growth, validates energy security, and alleviates poverty. Renewables promote cleaner production,

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and the ever-increasing carbon emissions can be reduced by switching renewables [14]. Among renewables, nuclear energy resources have fewer environmental effects concerning fossil energy (coal, gas, and oil) resources. From the past decades, nuclear energy is becoming a potential energy source that helps mitigate emissions [13]. Nuclear energy assists in environmental protection and also foreign dependency. Hence, nuclear energy resources are crucial in helping to deal with problems of energy security and environmental degradation [15,16] while also being effective in pollution reduction [17]. Alternatively, nuclear energy raises pollution as it discharges emissions [12] that may be corroborated with the emission of radioactive substances and nuclear waste management (handling and disposal) [18]. Nuclear energy and pollution nexus is unclear and demands further investigation; this study assesses nuclear energy and CO_2 emissions nexus within the PHH framework in China.

This study seeks to contribute to the literature by assessing the role of nuclear energy jointly with FDI in a framework of the so-called PHH for China. To our knowledge, this study is the first to address this issue. Second, the study addresses the PHH considering the significance of nuclear energy consumption. It is worth investigating China's PHH as developed countries might transfer their polluting industries to China and worsen environmental quality [19]. The findings of this study will divulge whether the Chinese economy differentiates from other economies, particularly developing and emerging economies, concerning the role of nuclear energy consumption on environmental quality. Moreover, by employing a dynamic autoregressive distributed lag (DARDL) approach for empirical estimation, it is able to counter counterfeit effects of independent variables on the dependent variable. The DARDL estimation technique helps visualize the imitated changes in the response variables that are because of a regressor.

The remaining study is divided as follows: Section 2 presents the review of earlier work on the nexus between nuclear energy and CO_2 emission; Section 3 explains the method used in the study and provides detail about the data; Section 4 analyzes and discusses the results; and Section 5 concludes the study with policy suggestions.

2. Literature review

Energy is a significant factor in producing goods and services and contributes to economic growth. However, in the literature, energy is considered the main determinant of environmental pollution [20–24]. Because of its adverse environmental effects, countries are globally shifting toward clean and renewable energy sources. Among these, nuclear energy can fulfill rising energy demands and clean the environment, even though its environmental impact is not clear because of divergent outcomes in previous studies. The literature is split concerning the environmental impact of nuclear energy. Some studies articulate that nuclear energy is environmentally beneficial. For instance, Baek and Pride [25] debated the influence of nuclear energy on pollution in the top six nuclear-producing countries and concluded that nuclear energy diminishes environmental pollution for all sample countries. In Japan, Ishida [26] publicized the positive role of nuclear energy in mitigating carbon emissions. In a study for China, Dong et al. [27] considered the effects nuclear energy on environmental pollution taking fossil fuels and renewable energy into account across 1993–2016. Results indicated the existence of an environmental Kuznets curve (EKC) hypothesis and concluded that nuclear energy positively contribute to pollution mitigation. Marques et al. [28] evaluated the associations between nuclear energy generation, economic output and CO_2 emissions employing monthly data between 2010 and 2014 in France. The study added positive role in contributing economic growth and reduces pollution. Furthermore,

another study in France [29] projected the EKC hypothesis controlling the role of electricity generation from nuclear energy for the data spanning 1960–2003 and concluded that nuclear energy contributes to pollution mitigation and invalidated the EKC hypothesis. Moreover, Iwata et al. [30] conducted a study for 11 Organisation for Economic Co-operation and Development (OECD) countries considering the nexus between electricity generation from nuclear sources for 1960–2003. Findings revealed that nuclear energy lowers carbon emission only in Finland, Japan, Korea, and Spain. Baek and Kim [31] considered the important of nuclear energy within framework for in Korea for the data between 1971–2007 and 1978–2007. The study suggests nuclear energy reduce environmental pollution with the confirmation of the EKC hypothesis in both the short and long runs. In a study for 35 developed countries Akhmat et al. [32] concluded that nuclear energy is beneficial for the environment through reducing GHGs. In a study for the US, Baek [13] documented the importance of renewables in air quality for the data from 1960 to 2010, and it was estimated the beneficial role of nuclear energy in lessening environmental pollution. Baek and Pride [25] originated that nuclear energy contributes to carbon emission reduction in the US, France, Japan, Canada, Spain, and Korea. A study in China [33] utilized an input distance function and found that nuclear energy is a better alternate for fossil fuels as compared with renewable energy because nuclear energy has a more reducing effect on CO_2 emissions. For a panel of 12 major nuclear-generating countries, Baek [19] confirmed nuclear energy help in lowering carbon emission, and no support was found for the EKC hypothesis. In contrast Lee et al. [34] validated the EKC hypothesis for France, Germany, and Switzerland and highlighted the advantageous effect of nuclear energy pollution mitigation. The similar results was revealed by Lau et al. [11] for OECD countries in a recent study.

In the second strand of research, it is found that either nuclear energy contribution to pollution or its influence is insignificant on environmental pollution. Sarkodie and Adams [18] studied the effects of nuclear energy, institutional quality, renewable energy, and CO_2 emissions for data spanning between 1971 and 2017 in South Africa. The results reveal that nuclear energy escalated pollution with the support of the EKC hypothesis. Furthermore, for the case of Pakistan, Mahmood et al. [12] considered the role of nuclear energy and carbon emission between 1973 and 2017. The results designated the detrimental effect of nuclear energy on pollution. For developing and developed countries Alam [35] analyzed the influence of nuclear energy on environmental pollution between 1993 and 2010. The result of the study confirmed that nuclear energy do not take part in reducing emissions for developing countries, whereas one-way causality was achieved running from nuclear energy to carbon emissions. However, Jaforullah and King [36] established an insignificant relationship between nuclear energy consumption and pollution, and Al-Mulali [37] found similar results for 30 major nuclear energy-consuming countries. Contrarily, Mbarek et al. [38] found nuclear energy does not play any significant role in carbon emission reduction and could not find proof for the EKC hypothesis in a panel of developing and developed countries. Similarly, Saidi and Ben Mbarek [15] found the same results on evidence for nine developed countries. Likewise, Jin and Kim [39] acquired similar results for 30 countries between 1990 and 2014. Additionally, they confirmed the feedback hypothesis between nuclear energy consumption and carbon emissions in the short run.

Earlier studies have investigated the nexus between nuclear energy and CO_2 emissions, providing a lot of information. However, because of issues in employing modeling approaches and variable uses, properly constructed, and comprehensive analyses are limited. This study employed more advanced technique for time

series data to investigated nuclear energy and emissions nexus within framework of Pollution Haven Hypothesis.

3. Materials and methods

Because earlier research mostly focused on the EKC theory accounting for nuclear energy to derive an empirical model, they did not investigate the more precise form of model specifications. To develop an economic model in this study, the standard model of the nuclear energy–income–CO_2 emissions nexus is extended to consider the importance of FDI in the framework of the PHH, which is expressed as follows:

$$Ln\,(CO_2)_t = \beta_0 + \beta_1\,Ln\,(GDP)_t + \beta_2\,Ln\,(NUC)_t + \beta_1\,Ln\,(FDI)_t + u_t \quad (1)$$

where, $(CO_2)_t$ is the carbon dioxide emissions; GDP is the gross domestic product; NUC shows nuclear energy consumption; and u_t is the stochastic error term capturing the effect of other factors on CO_2 emissions.

Meanwhile for empirical estimation, current research work applies a DARDL simulation model, which can be articulated as

$$\Delta \ln(CO_2)_t = \alpha_0 \ln(CO_2)_{t-1} + \beta_1 \Delta \ln(GDP)_t + \theta_1 \Delta \ln(GDP)_{t-1}$$
$$+ \beta_2 \Delta \ln(NUC)_t + \theta_2 \Delta \ln(NUC)_{t-1} + \beta_3 \Delta \ln(FDI)_t + \theta_3 \Delta \ln(FDI)_{t-1}$$
$$(2)$$

where, α is the coefficient of the response variable; (β_0) is intercepted; $t - 1$ shows the regressors; and Δ is the first difference operator time t. Inbound testing procedure when the calculated F-value and t-value exceed the upper bound critical value [I(1)], followed by approximate p-values, this confirms the rejection of the null hypothesis of no co-integration. An innovative simulation method proposed by Jordan and Philips [40], which fixes the complexities issue in the already prevailing method of the autoregressive distributed lag (ARDL) investigating the long- and short-run dynamics. For the application of the DARDL simulation model, it is necessary that the outlined variables of the study must hold an integration order of one and be co-integrated. The DARDL simulation algorithm uses up to 5000 simulations of the vector of parameters using the multivariate normal distribution. Before long- and short-run estimations, it is essential to verify co-integration among outlined variables. Doing this bound testing, the co-integration procedure by Pesaran et al. [41] is employed utilizing the pathway of Kripfganz and Schneider [42] for critical values that are also supported by probability values. The recent energy literature adopted this process [43–45]. This is considered the most appropriate for lower and upper critical values estimation as it is independent whether the date series is stationary at level, I(0), or at the first difference, I(1). The regression table helps to calculate asymptotic critical values directly for any number of long-run-forcing variables and several cases of unrestricted or restricted deterministic model components. The critical values selection relies on presenting more consistent and vigorous results for a small finite sample size. The empirical strategy adopted is consistent with current literature [44,46].

The present study utilizes the time series data of China spanning from 1994Q1 to 2018Q4. This study uses carbon emission as a response variable, which is measured in tons. However, carbon emission is the function of nuclear energy per capita GDP and nuclear energy. Nuclear energy is taken in million tons of oil equivalents. FDI is a net inflow of percentage of GDP, and per capita GDP is in US dollars. Nuclear energy and carbon emission were converted to per capita divide by the total population. Data on carbon emission and nuclear were gathered from British Petroleum statistics,

and data on FDI and per capita GDP were drawn from the World Bank database. The data is graphical shown in Fig. 1 and the descriptive statistics are presented in Table 1.

4. Results

The seminal step of long-run econometric analysis is to observe the stationary properties of the indicated variables by employing the Augmented Dickey–Fuller unit root test and the Phillips–Perron unit root test (Table 2). Result confirms that the null hypothesis cannot be rejected at the level for the variables under investigation, but the null hypothesis that the variable unit root at the first difference is rejected. Meaning that variables under consideration are stationary at the first difference, i.e., [I(1)].

Next is confirming the level of the relationship among core variables by employing the bound test method by Pesaran et al. [41] using [42] for critical values. According to the estimated values in Table 3, null hypothesis of no co-integration is rejected for both t-values and F-values. In other words, there exists a co-integration between the core variables.

The bound testing procedure by Pesaran et al. [41] is calculated for the robust check of co-integration results (Table 4). The calculated F-value exceeds the upper bound values. Alternatively, bound testing confirms co-integration among variables of the study.

After confirmation of stationary level and co-integration among indicated variables, the following step is to investigate the long- and short-run equilibrium relationship between per capita GDP, nuclear energy, FDI, and carbon emissions. Table 5 shows outcomes of the DARDL estimation results of the long- and short-run equilibrium relationship between underlying variables of the study. The estimated coefficient of income is positive and significant, which signposts the detrimental effect of income on environmental pollution. Furthermore, the environmental impact of nuclear energy consumption is found, and Table 5 has outlined the estimated coefficient of per capita GDP, FDI and nuclear energy is negative and significant. Table 4 indicates the negative and significant coefficient of FDI on CO_2 emissions in the long run. Table 4 reports the short-run coefficient of the per capita GDP, FDI, and nuclear energy impacts on emissions. The coefficient of per capita GDP in the short run is positive and significant. The diagnostic test results in Table 5 suggest that the model of the study is free from the issue of heteroscedasticity and serial correlation.

For the robust check, the ARDL method of Pesaran et al. [41] is employed (Table 5). Accordingly, per capita GDP (*Ln* Y) contributes to pollution, and FDI and nuclear energy play positive roles in mitigation of emissions. The results generated by ARDL are similar to those of DARDL, validating the findings and confirming reliability.

Automatically plotting the changes in dependent variables due regressor is one of the features of the DARDL simulation method. Fig. 1-3 show the visual representation of the changes that occur in the response variable due to independent variables. Neither positive nor negative shocks in GDP influence emissions. The positive and negative shocks in FDI can either negate or increase emissions; positive shocks reduce emissions, whereas negative shocks immediately escalate. The decreasing trend in emissions can be linked with clean technology transfer to China via FDI inflow. Likewise, positive shocks in nuclear energy consumption mitigate emissions, whereas negative shocks contribute to emissions (see Fig. 4).

5. Discussion

The role of per capita GDP in emissions is the same for both the short- and long-run. The policy design of the role of GDP for the
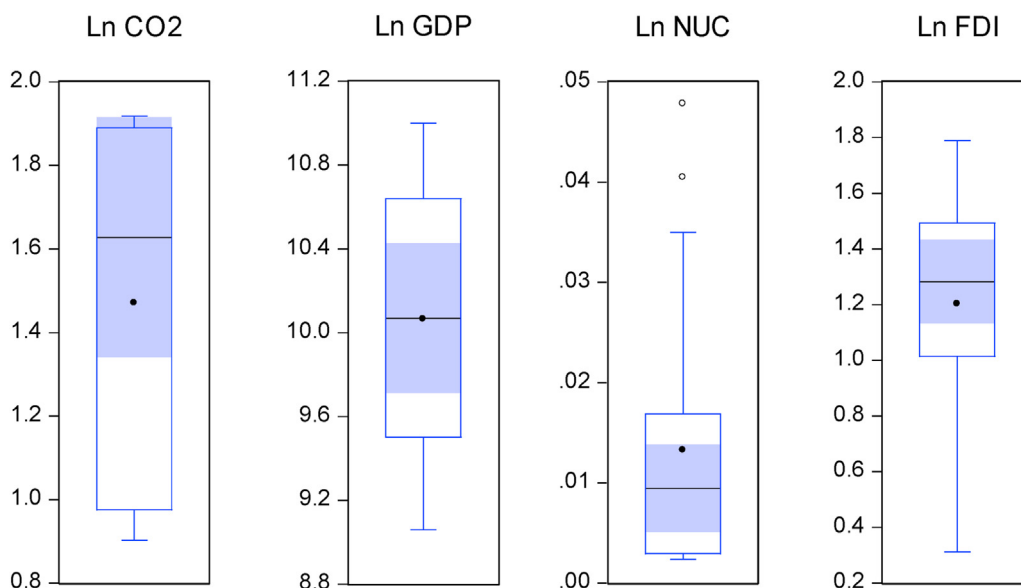
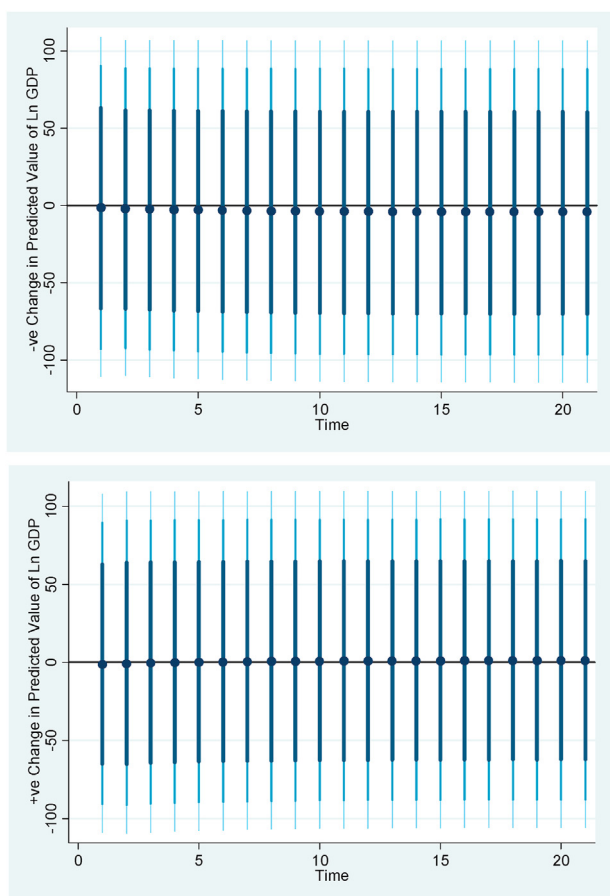**Fig. 1.** Box plot of the *Ln* CO$_2$, *Ln* GDP, *Ln* NUC, and *Ln* FDI.

Fig. 2. Shows $\pm$ change in predicated value of *Ln* GDP.

short run can be extended in the long run. Another interest is the impact of nuclear energy on carbon emission being negative and significant, recommending that nuclear energy is environmentally beneficial. Findings back the claim that China's nuclear operations generate almost no CO$_2$ emissions; switching to nuclear power

could contribute to pollution mitigation [13]. The diversification of energy supplies to renewable energy is necessary for China [47]. Nevertheless, in China, nuclear energy is a low-carbon energy source, but importantly, its electrical generation needs a great deal of attention concerning safety matters. The radioactive waste management and installation of the nuclear plant need to be treated carefully to circumvent unwanted accidents that may have environmental and health impacts [11]. Innovation in the energy sector would be a sensible choice to reduce emissions [48,49]. The outcomes from this study validated results from earlier works [17,27]. However, several studies on nuclear energy and CO$_2$ emissions nexus have produced dissimilar results because of poor nuclear waste disposal management practices [12,18,50].

The positive long-run impact of FDI on emission endorses the fear on the free flow of international trade and investment flows. This could be explained as the dominant technique effects of FDI over scale effect since it is a sign of country's development. Through the technique effect, environmental quality improves with the use of advanced technology that produces clean goods. The technique effect denotes when FDI raises income, emission intensity may fall since environmental quality is a normal good [20]. The positive role of FDI means the country is getting benefits from the influxes through the adoption of cleaner production technologies. It is attributed to relatively stringent environmental regulations and laws in China [2]. Meanwhile, this finding is contrary to those of [44,47] and who found a negative role of FDI in pollution. The possible reason could be the longer dataset used in the current study, which means that with time China's policies for FDI are improving. The environmental impact of FDI is positive and significant, implying that FDI contributes to pollution in the short run. The environmental impact of FDI varies across the short and long runs. According to the result of the clean role of FDI, the environment needs long-run planning. Likewise, nuclear energy do not play role in emissions in the short run, meaning it needs time to play its role in mitigating carbon emissions.

6. Conclusions and policy implications

This study modeled FDI and nuclear energy impacts on carbon emission controlling for the role of per capita GDP in China. The

Table 1
Descriptive statistics.

	Mean	Median	Maximum	Minimum	Std. Dev.
Carbon emissions	4.705368	5.093636	6.805554	2.466805	1.783824
Foreign direct investment	3.541797	3.609100	5.987156	1.367677	1.145625
GDP	28090.18	23627.69	59811.60	8610.277	16461.14
Nuclear energy	0.013247	0.009466	0.047824	0.002410	0.012592

Table 2
Unit root test result.

	Phillips–Perron		Augmented Dickey–Fuller	
	Level	First difference	Level	First difference
Variables	Test statistic	Test statistic	Test statistic	Test statistic
$Ln\ CO_2$	−0.880 [0.776]	−4.285* [0.003]	−1.433 [0.548]	−4.277* [0.003]
Ln GDP	−0.953 [0.752]	−4.419* [0.002]	−0.787 [0.803]	−4.418* [0.002]
Ln FDI	−0.549 [0.864]	−5.257* [0.000]	−0.680 [0.833]	−5.155* [0.000]
Ln NUC	7.582 [1.000]	−4.299* [0.003]	−0.028 [0.946]	−4.466* [0.002]

Note: * shows significance at the 1% level.

Table 3
Co-integration test results.

Model	Statistic		10%		5%		1%		p-values	
			I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
$Ln\ CO_2$ = f (Ln GDP, Ln FDI, Ln NUC)	F	4.601	3.153	4.464	3.979	5.530	6.139	8.292	0.031	0.091
	T	−3.488	−2.573	−3.479	−2.974	−3.948	−3.832	−4.954	0.019	0.099

Table 4
Co-integration test result.

Model	F-statistic	Decision
$Ln\ CO_2$ = f (Ln GDP, Ln FDI, Ln NUC)	8.292	Co-integration
Significance	I_0 Bound	I_1 Bound
10%	2.72	3.77
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

Table 5
DARDL and ARDL estimation results.

Regressor	Dynamic ARDL	ARDL
	Coefficient [p-values]	Coefficient [p-values]
$Ln\ CO_{2(t-1)}$	1.240* [0.000]	−0.730† [0.049]
$Ln\ Y_{t-1}$	0.555‡ [0.0543]	0.809* [0.000]
$\Delta\ Ln\ Y_t$	0.293‡ [0.051]	2.255* [0.003]
$Ln\ FDI_{t-1}$	−0.1501** [0.021]	−0.304* [0.000]
$\Delta\ Ln\ FDI_t$	0.158‡ [0.075]	0.173‡ [0.085]
$Ln\ NUC_{t-1}$	−9.573* [0.004]	−2.847** [0.039]
$\Delta\ Ln\ NUC_t$	0.473 [0.849]	−1.022 [0.876]
Constant	2.498‡ [0.086]	−7.334* [0.000]
R^2	0.99	0.99
Sim	5000	–
F-statistic	358.04 [0.000]	748.28 [0.000]
Diagnostic test		
$\chi^2_{LM\text{-}ARCH}$	0.085 [0.770]	2.809 [0.152]
χ^2_{hetero}	0.41 [0.5209]	0.132 [0.719]

Note: *,** and †, significant at 1%, 5% and 10% levels, respectively.
Y,; FDI, foreign direct investment; NUC, nuclear energy consumption; $\chi^2_{LM\text{-}ARCH}$,; χ^2_{hetero},; ARDL,.

Fig. 3. Shows ± change in predicated value of Ln FDI.

PHH is tested in the presence of nuclear energy employing the DARDL simulation method from 1994Q1 to 2018Q4. The bound testing method confirmed co-integration among the indicated
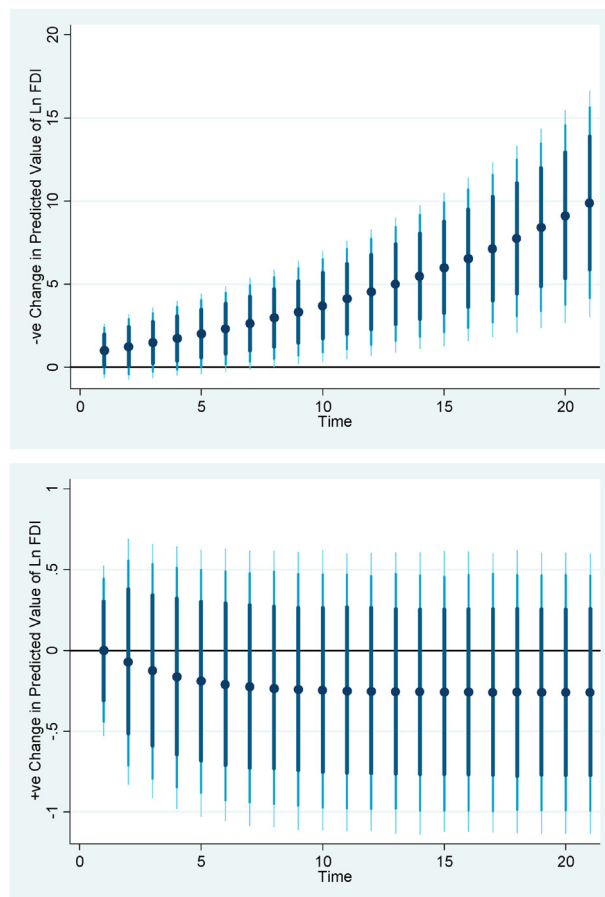
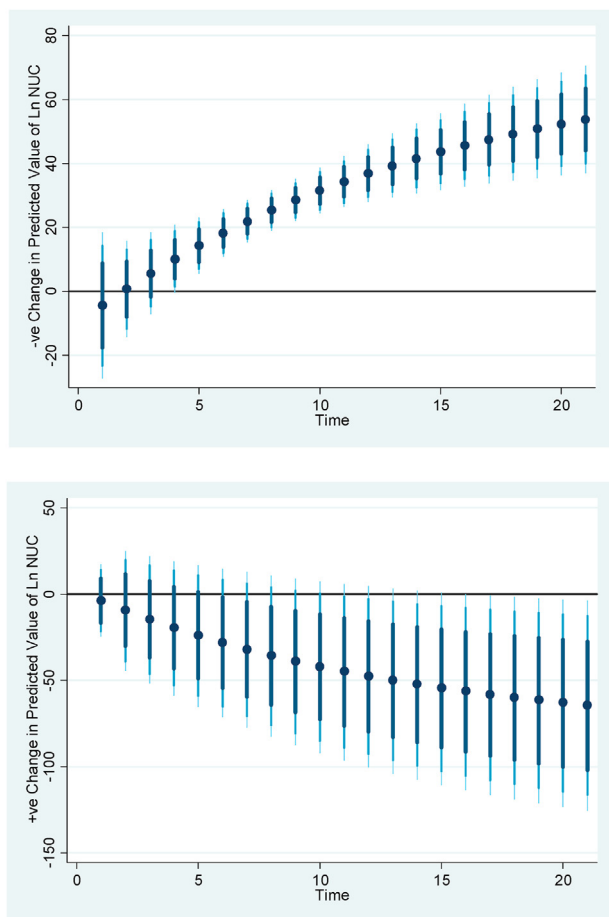**Fig. 4.** Shows ± change in predicated value of *Ln* NUC.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

variables of the study. The DARDL results confirm the absence of the PHH, suggesting that FDI improves China's environmental quality through the reduction of carbon emissions. Nuclear energy behaves as a clean energy source that reduces emissions.

Results suggest several policy directions that should be designed to open up and attract more foreign investment. The inflow of cleaner technology and trade goods would benefit the environment. Nuclear electricity should add more share to the energy mix to make China a free carbon economy. Additionally, generation of electricity from nuclear energy could be an important step to reduce the increased dependence on non-renewable energy and energy imports. Clean energy shared approximately 13.0% of China's total energy mix in 2016. For climate change mitigation, more efforts are required for the development of clean energy [27]; for instance, the Chinese government should invite more foreign investment in the nuclear energy sector with long-term plans to increase generation of electricity. Undoubtedly technology related to nuclear energy would promote the country's status and importance of alternate electric supply sources, promoting economic growth alongside contributing to social and sustainable environmental improvement. Nuclear energy is a cheaper energy source that ensures energy security and has a positive environmental role by reducing air pollution and ozone depletion. It can be appealing for economic, social, and environmental purposes.

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