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Posted Date: 23 January 2025

doi: 10.20944/preprints202501.1779.v1

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Asymmetric Effects of Fiscal Policy and Foreign Direct Investment Inflows on CO2 Emissions—An Application of Non-Linear ARDL

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Abstract: Research on the impact of fiscal policy and foreign direct investment (FDI) on environmental quality has yielded conflicting results regarding their effects on carbon dioxide emissions. To further explore the asymmetric influences of these two critical factors on environmental quality, we employ a nonlinear ARDL approach to examine how fiscal policy (GOEX), FDI inflows, and other drivers of CO2 emissions, such as trade openness, financial development, and economic growth, affect environmental quality in Vietnam from 1990 to 2022. Our findings indicate that a positive shock in GOEX results in decreased emissions, whereas a negative shock in GOEX leads to increased emissions, challenging previous research suggesting that higher expenditures typically harm the environment. We also observe that positive changes in FDI result in higher CO2 emissions, whereas negative FDI shifts have no statistically significant impact. Additionally, our study revealed that trade openness improves environmental conditions, whereas economic growth and financial development contribute to increased CO2 emissions. The responses of CO2 emissions to the asymmetric effects of fiscal policy, FDI inflows, and other determinants in the short run last in the long run. These insights are valuable for policymakers to develop environmental sustainability strategies to mitigate climate change by addressing fiscal policies and other determinants of CO2 emissions.

Keywords: fiscal policy; foreign direct investment inflows; CO2 emissions; non-linear ARDL

1. Introduction

The global issue of climate change demands swift action to shift economies towards a low-carbon future. According to the Intergovernmental Panel on Climate Change [1] report, global temperatures are projected to rise by 1.5°C between 2030 and 2050, with further increases likely if greenhouse gas emissions are not reduced. There is a strong consensus among economists and scientists that global warming and climate change pose significant threats to economic growth, people's livelihoods, and human survival [2–4].

As emissions rise globally, research on their causes, especially the role of macroeconomic policies, is expanding. Fiscal policies, which are crucial for managing aggregate demand, economic growth, income, and inflation, are increasingly scrutinized for their environmental impacts. These policies could worsen and mitigate CO2 emissions. In the theoretical analysis of environmental fiscal reforms in India, [5] determined that environmental fiscal reforms offers a more efficient and cost-effective approach to improving environmental conditions compared to conventional regulatory measures. Few studies have focused on government spending as a tool for environmental management [6,7], while others have linked significant public expenditure to environmental harm [8–11]. Some studies have reported ambiguous results on the effects of fiscal policies on environmental quality [12,13], with limited investigations of the specific impacts of expansionary and contractionary fiscal policies on emissions.

It is crucial to explain the impact of fiscal policy instruments on environmental quality. Government spending can influence carbon emissions sources, thereby negatively affecting the environment [14]. [15] discuss mechanisms through which government expenditure impacts environmental quality. Health and educational spending can increase consumer income and potentially enhance environmental quality through income effects. Conversely, substantial government consumption can improve administrative and environmental controls and strengthen institutions that enhance environmental quality. Thus, government spending has a positive effect on environmental pollution. However, [6] also show that fiscal policy mechanisms include technique, income, and composition effects, potentially suggesting favorable ecological effects of fiscal policy. The technique effect enhances labor efficiency, which is linked to higher health and education spending, thus reducing pollution. The income effect denotes an increased demand for environmental quality with increasing income levels. The composition effect involves public spending promoting human capital-related economic activities that are less environmentally harmful than those linked to physical capital.

The impact of Foreign Direct Investment (FDI) on carbon dioxide emissions is complex, as illustrated by the "Pollution Haven" and "Pollution Halo" Pollution Halo' hypotheses [16]. The "Pollution Haven" hypothesis suggests FDI from developed countries relocates to developing nations with lax environmental regulations, increasing CO2 emissions. This follows the comparative advantage theory, in which stricter regulations in developed countries raise production costs, prompting companies to move pollution-intensive operations to regions with looser standards. Conversely, the "Pollution Halo" hypothesis argues that FDI can improve environmental quality by introducing advanced technologies and management practices that reduce emissions. Proponents claim that FDI using cleaner technologies fosters eco-friendly growth and mitigates carbon emissions.

The World Bank identifies Vietnam as the country most impacted by air pollution among 10 nations worldwide [17], with environmental deterioration emerging as a critical concern [18]. As a rapidly growing Southeast Asian economy striving to achieve a high-middle-income status and become a modern industrialized nation by 2035, Vietnam faces challenges in balancing economic growth with environmental conservation [19]. A country's shift from a market economy to industrialization has negatively affected its environment and natural resources. Accelerated economic expansion, urban development, and industrial growth have led to increased energy use and environmental strain. The power sector's reliance on fossil fuels contributes to approximately two-thirds of the nation's greenhouse-gas emissions [17].

Since 1990, Vietnam's fiscal policy has supported national development through strategies such as economic revitalization, the State Budget Law, a Medium-term Expenditure Framework, and tax reforms such as reducing corporate income tax rates and introducing value-added tax. The Public Debt Management Law (2013) and Public Investment Law (2016) aim to enhance public debt management, fiscal sustainability, and investment transparency. Vietnam has also invested in infrastructure, education, and healthcare to boost its economic growth. Additionally, tax reforms and incentives have been introduced to attract foreign investment while maintaining a low public debt-to-GDP ratio [20].

Research suggests that the effects of fiscal policy on environmental quality and FDI inflows vary by pollutant type, region, and income level, necessitating further empirical studies to understand the relationship between fiscal policy, FDI inflows, and the environment. This study examines the dynamic connections between fiscal policy via government expenditure, FDI inflows, and CO2 emissions in Vietnam from 1990 to 2022. Furthermore, negative and positive shocks to Vietnam's government expenditure can lead to lower and higher CO2 emissions, respectively. These findings are not in line with previous research that has linked increased spending on environmental degradation. Additionally, an increase in FDI correlates with decreased CO2 emissions, whereas a reduction in FDI has no significant effect on emissions levels. Furthermore, trade openness improves environmental quality by enhancing energy efficiency, whereas economic growth and financial development are associated with higher CO2 emissions.

 doi:10.20944/preprints202501.1779.v1

Our findings contribute to the existing literature by examining the asymmetrical effects of fiscal policy and FDI inflows on carbon dioxide emissions, considering trade openness, economic growth, and financial development as control variables. Unlike most previous studies, this study addressed the asymmetric impact of fiscal policies and FDI on environmental quality. Additionally, this study employs a nonlinear Autoregressive Distributed Lag (ARDL) approach to assess these effects in Vietnam's emerging economy. The nonlinear ARDL method offers several advantages. It captures both positive and negative variable effects simultaneously, performs well with limited sample sizes, accommodates variables integrated at different orders, and provides robust results through a dynamic error correction.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature. The third section elaborates on the data sources, variable estimation techniques, and methodological approaches. Section 4 presents the results and their analyses. Section 5 presents the conclusions and offers policy recommendations.

2. Literature Review

2.1. Fiscal Policy and Environmental Quality

Environmental and energy economists have shown a growing interest in the link between fiscal tools and environmental quality, although empirical research is still limited. Fiscal measures can both increase and decrease CO2 emissions, thereby influencing environmental quality. Few studies have analyzed government expenditure as a fiscal tool for managing environmental quality [6,7]. [6] identified four ways fiscal spending impacts atmospheric pollution: "scale, composition, technique, and income" effects. The scale effect pertains to environmental pressure from rapid economic growth. The composition effect involves shifting from physical capital-intensive inputs to less-polluting human capital-intensive inputs. This technique results in more efficient labor through improved practices. The income effect reflects the desire for a better environment as income increases. [5] conducted a theoretical analysis of environmental fiscal reforms (EFR) in India and concluded that EFR could achieve more efficient and cost-effective environmental improvements than traditional regulations.

[21] focuses on factors affecting carbon emissions, such as economic growth, political and economic freedom, population growth, urbanization, and energy use. [22] discovered no significant effect on CO2 emissions, but found a notable reduction in SO2 emissions from government expenditures in 77 economies (1980-2000), with SO2's impact shifting from negative to positive as income levels rose. Studies by [15] and [22] neglected the asymmetric relationships between fiscal policy and CO2 emissions. [23] found that vehicle registration taxes reduced carbon emissions in the automotive sector of 15 EU countries from 2001 to 2010. Current research has inadequately addressed the complex relationships between fiscal policies and CO2 emissions, neglecting both the positive and negative aspects.

[9] examined Turkey's fiscal policy impact on environmental quality from 1960 to 2013, concluding that fiscal measures reduce carbon emissions and are crucial for environmental management. Similarly, [11] studied China's fiscal policy tools and environmental degradation from 1980 to 2016 and found that fiscal policies significantly worsened long-term environmental quality, implying that expansionary fiscal measures harmed the environment. A limitation of these studies is the assumption of a symmetric relationship between fiscal policy instruments and environmental quality.

[24] reveal conflicting results among ASEAN countries regarding the asymmetric impacts of fiscal policies on CO2 emissions. In the long run, expansionary fiscal policy (positive government spending shocks) increased CO2 emissions in Indonesia, the Philippines, and Thailand, but had no significant effect in Malaysia and Singapore. Contractionary fiscal policy (negative government spending shocks) decreased CO2 emissions in Indonesia, the Philippines, and Singapore but increased emissions in Malaysia. These divergent outcomes suggest that the environmental impacts

of fiscal policies vary considerably across ASEAN nations. In the short run, the effects of fiscal policies on CO2 emissions also differ among countries. Expansionary fiscal policies positively influenced emissions in all ASEAN economies, except Malaysia. Contractionary fiscal policies negatively impacted emissions only in Malaysia and the Philippines. These contrasting short- and long-term effects across countries highlight the complex relationship between fiscal policy and environmental quality in the ASEAN region.

Given these conflicting results, there is a clear need for further research on the ecological impacts of fiscal policies. Future studies should investigate the underlying factors contributing to these divergent outcomes across countries, such as differences in economic structures, the energy mix, and environmental regulations. Additionally, research should explore how the specific attributes of government spending in each country can affect emissions. More insights into Vietnam would be valuable for designing more effective and targeted fiscal policies to improve environmental quality in ASEAN and other countries with similar economic and environmental backgrounds.

2.2. Fiscal Policy and Environmental Quality

The "Pollution Haven" pollution haven hypothesis introduced by [25] suggests that economic globalization drives industrialized nations to transfer high-pollution industries to developing countries with lax environmental regulations. This aligns with the comparative advantage theory [26,27], which argues that stringent environmental regulations in developed countries increase production costs, leading manufacturers to relocate pollution-intensive operations to nations with looser regulations, a phenomenon also termed the "industrial flight hypothesis" [28–32]. [33] proposed the "Pollution Halo" hypothesis, suggesting that FDI improves host countries' environmental quality through advanced technologies and management experience, which was confirmed by [34–36], and [37] in South Africa from 1990 to 2018. However, [38] observed heterogeneous technical spillover effects of FDI across Chinese provinces, indicating the coexistence of "Pollution Haven" and "Pollution Halo" effects. [39] attributed the "Pollution Haven" in China to the energy rebound effect from FDI-induced energy efficiency improvements. The overall impact of FDI on China's carbon emissions remains uncertain because these studies do not address the scale and industrial structure effects of FDI.

Foreign direct investment (FDI) has been hailed as a potential catalyst for environmental improvements in host countries. The transfer of advanced technologies and management practices from multinational enterprises can facilitate the adoption of cleaner production processes and energy-efficient techniques [40]. Moreover, FDI inflows can stimulate economic growth, which may lead to increased demand for environmental quality and stricter environmental regulations [41]. Consequently, FDI could potentially reduce CO2 emissions and improve environmental quality in the recipient countries, especially in the long run [42]. Conversely, FDI may exacerbate environmental degradation through the pollution haven hypothesis, whereby multinational corporations relocate their polluting activities to countries with lax environmental regulations [43]. Furthermore, the scale effect of FDI-induced economic growth could outweigh the technique effect, leading to an overall increase in CO2 emissions [44].

Given the contrasting potential impacts of FDI on environmental quality, there is a compelling need to investigate the asymmetric effects of FDI on CO2 emissions. Negative and positive shocks or fluctuations in FDI inflows may have different impacts on a country's environmental performance. Negative FDI shocks, such as the divestment or downsizing of foreign firms, could lead to job losses, reduced economic activity, and potentially weaker environmental regulations, exacerbating CO2 emissions [45]. Conversely, positive FDI shocks, such as increased foreign investment in cleaner technologies and sustainable practices, may facilitate the transition towards a low-carbon economy [46]. By explicitly accounting for these asymmetries, policymakers can devise targeted strategies to mitigate the adverse environmental consequences of negative FDI shocks while capitalizing on the potential benefits of positive FDI inflows [47]. Such an asymmetric analysis is crucial for achieving sustainable economic development while safeguarding environmental quality.

 doi:10.20944/preprints202501.1779.v1

2.3. *Other Factors Responsible for Carbon Emissions*

2.3.1. Financial Development and Carbon Emissions

Literature has found that financial development has a direct or indirect impact on carbon Some studies suggest that financial development reduces the cost of credit, facilitating loans [48] and consequently boosting industrial output and development. This positive association with energy consumption is supported by [49], indicating that a developed financial sector stimulates energy use and carbon emissions [50,51]. [52] found that in Central and Eastern Europe's frontier economies, financial development increased credit availability for energy-intensive products such as houses, cars, and appliances, leading to higher energy use and carbon emissions. Conversely, [53] argued that financial development reduces intermediary costs and risks for investors in clean energy projects, enhancing R&D investment in low-carbon technologies, which is crucial for reducing carbon emissions. However, some scholars question whether financial development can reduce carbon dioxide emissions [54]. Therefore, the relationship between financial development and carbon emissions requires an empirical investigation across various contexts and variables.

2.3.2. Trade Openness and Carbon Emissions

Trade openness and development not only attract foreign direct investment and enhance R&D capabilities [55], but also boost energy efficiency and reduce carbon emissions [56]. They improved their environmental governance [57], per capita carbon emissions, and elevated global environmental standards [58]. Moreover, international trade facilitates the spread of eco-friendly products and services, helping nations transition to low-carbon economies and tackle global carbon reduction [59]. In China, trade has been crucial for economic growth, advancing pollution control and environmental management techniques [60]. However, the relationship between trade openness and carbon emissions has been debated, with studies showing mixed effects. [61] found trade openness achieves carbon neutrality in wealthier countries but not in poorer ones, echoing [62] on how income influences emissions. Lopez [63] noted trade increases pollution and resource use due to its scale effect, supporting the environmental Kuznets hypothesis. The impact of trade liberalization varies by a country's income and economic structure, with [64] concluding it reduces emissions in high-income nations only.

2.3.3. Economic Growth and Carbon Emissions

Economic growth positively affects CO2 emissions across countries, as evidenced by numerous empirical studies using diverse methodologies. This relationship has been identified in Nigeria [65], OECD countries [66], Egypt [67], South Africa [68], Turkey [69], and China [70] using estimators such as ARDL, FMOLS, and DOLS with data spanning several decades. [71] and [72] found that economic growth increases CO2 emissions in various countries and regions, such as 20 African countries, MINT countries, GCC countries, G7 countries, and APEC countries, using different econometric approaches, including ARDL, STIRPAT, and DSUR, for different time periods ranging from 1980 to 2018

3. Model and Methodology

Based on previous studies on the determinants of CO2 emissions [10,73], we modeled CO2 emissions as a function of the variables under consideration as follows:

$$CO_2 = f(TRADE, CREDIT, FDI, GOEX, GDPPC) \quad (1)$$

where CO2, TRADE, CREDIT, FDI, GOEX, and GDPPC represent carbon dioxide emissions, trade openness, financial development, foreign direct investment inflows, fiscal policy, and economic growth, respectively. We claim that these variables are decisive production factors and major drivers of CO2 emissions. Variables in the time-series data undergo standardization, and natural logarithms

 doi:10.20944/preprints202501.1779.v1

are employed to generate accurate estimates [74]. Table 1 provides a detailed description of the study variables.

Table 1. Variable description.

Symbol	Variables	Definition	Sources
CO2	Per capita carbon dioxide	Kt of CO2 emissions	WDI
TRADE	Trade openess	The sum of import and export (% of GDP)	WDI
CREDIT	Financial development	The volume of domestic credit to private sector (% of GDP)	WDI
FDI	Foreign direct investment inflow	Foreign direct investment inflows (% of GDP)	WDI
GOEX	Fiscal policy	Government expenditure (% of GDP)	WDI
GDPPC	Economic development	GDP per capita (constant $US 2010)	WDI

This research employs the augmented Dickey Fuller (ADF) [75] and Phillips Perron (PP) [76] tests to examine unit roots. To assess nonlinearity, the study utilizes the BDS test, which was published as [77]. The logarithmically transformed Equation (1), incorporating both positive and negative changes in fiscal policy and foreign direct investment inflows while controlling other determinants of carbon emissions, can be expressed as:

$$CO_2 = \alpha_0 + \beta_1^+ GOEX_t^+ + \beta_2^- GOEX_t^- + \beta_3^+ FDI_t^+ + \beta_4^- FDI_t^- + \beta_5 TRADE_t + \beta_6 CREDIT_t + \beta_6 GDPPC_t + \varepsilon_t \quad (2)$$

In this equation, the intercept is represented by α, the coefficients of the variables are denoted by β, and ε signifies the error term at time t. This research divides fiscal policy and foreign direct investment inflows into two separate components: a positive partial sum and a negative partial sum. From these, four new time series were generated as follows:

$$FDI_t^+ = \sum_{n=1}^{t} \Delta FDI_t^+ = \sum_{n=1}^{t} \max(\Delta FDI_t^+, 0) \quad (3)$$

$$FDI_t^- = \sum_{n=1}^{t} \Delta FDI_t^- = \sum_{n=1}^{t} \min(\Delta FDI_t^-, 0) \quad (4)$$

$$GOEX_t^+ = \sum_{n=1}^{t} \Delta GOEX_t^+ = \sum_{n=1}^{t} \max(\Delta GOEX_t^+, 0) \quad (5)$$

$$GOEX_t^- = \sum_{n=1}^{t} \Delta GOEX_t^- = \sum_{n=1}^{t} \min(\Delta GOEX_t^-, 0) \quad (6)$$

The nonlinear autoregressive distributed lag (NARDL) framework in Eq. (2) can be written as:

$$\Delta CO_{2,t} = \alpha_0 + \sum_{k=1}^{n} \theta_k \Delta CO_{2,t-k} + \sum_{k=0}^{n} \sigma_k^+ \Delta GOEX_{t-k}^+ + \sum_{k=0}^{n} \tau_k^- \Delta GOEX_{t-k}^- + \sum_{k=0}^{n} \cap_k^+ \Delta FDI_{t-k}^+ + \sum_{k=0}^{n} \emptyset_k^- \Delta FDI_{t-k}^- + \sum_{k=0}^{n} \aleph_k \Delta TRADE_{t-k} + \sum_{k=0}^{n} \forall_k \Delta CREDIT_{t-k} + \sum_{k=0}^{n} \aleph_k \Delta GDPPC_{t-k} + \omega_1 CO_{2,t-1} + \omega_2 FDI_{t-1}^+ + \omega_3 FDI_{t-1}^- + \omega_4 GOEX_{t-1}^+ + \omega_5 GOEX_{t-1}^- + \omega_6 TRADE_{t-1} + \omega_7 CREDIT_{t-1} + \omega_8 GDPPC_{t-1} + \varepsilon_t \quad (7)$$

The asymmetric influence of variables on carbon emissions was investigated using the nonlinear ARDL approach for several reasons: (i) it integrates nonlinear asymmetry and cointegration within a single equation; (ii) the NARDL model assesses how positive and negative changes in decomposed variables affect the dependent variable; (iii) it is suitable for small sample sizes; (iv) it offers flexibility by not requiring variables to be integrated in the same order; and (v) it functions as a dynamic error-correction representation, providing robust empirical results even with limited sample sizes.

The long-run symmetry ($\omega_4 = \omega_5$ for GOEX and $\omega_2 = \omega_3$ for FDI) and asymmetry ($\omega_4 \neq \omega_5$ for GOEX and $\omega_2 \neq \omega_3$ for FDI) are tested by using the standard Wald test.

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Regarding the long-term asymmetric relationship between FDI and carbon emissions, a statistically significant positive coefficient ($\omega_2 > 0$) indicates that an increase in FDI (positive shocks in the partial sum of FDI) leads to higher carbon emissions. Conversely, a statistically significant negative coefficient ($\omega_3 < 0$) suggests that a decrease in FDI (negative shocks in the partial sum of FDI) results in a substantial rise in carbon emissions. Similarly, for the long-term asymmetric relationship between GOEX and carbon emissions, a statistically significant positive coefficient ($\omega_4 > 0$) implies that an expansionary fiscal policy (positive shocks in the partial sum of FDI) increases carbon emissions. In contrast, a statistically significant negative coefficient ($\omega_5 < 0$) indicates that a contractionary fiscal policy (negative shocks in the partial sum of FDI) significantly raises carbon emissions.

To calculate short-term NARDL elasticities by incorporating an error correction mechanism, researchers can employ the following equation:

$$\Delta CO_{2,t} = \alpha_0 + \sum_{k=1}^{n} \theta_k \Delta CO_{2,t-k} + \sum_{k=0}^{n} \sigma_k^{+} \Delta GOEX_{t-k}^{+} + \sum_{k=0}^{n} \tau_k^{-} \Delta GOEX_{t-k}^{-} + \sum_{k=0}^{n} \cap_k^{+} \Delta FDI_{t-k}^{+} + \sum_{k=0}^{n} \emptyset_k^{-} \Delta FDI_{t-k}^{-} + \sum_{k=0}^{n} \aleph_k \Delta TRADE_{t-k} + \sum_{k=0}^{n} \forall_k \Delta CREDIT_{t-k} + \sum_{k=0}^{n} \aleph_k \Delta GDPPC_{t-k} + \emptyset ECM_{t-1} + \varepsilon_t \quad (8)$$

In the Eq. (8), $\emptyset$ represents error correction term, which also shows the long-run equilibrium speed of adjustment after the shock in the short-run. Also, the short-run symmetry ($\sigma_k^{+} = \tau_k^{-}$ for GOEX and $\cap_k^{+} = \emptyset_k^{-}$ for FDI) and asymmetry ($\sigma_k^{+} \neq \tau_k^{-}$ for GOEX and $\cap_k^{+} \neq \emptyset_k^{-}$ for FDI) are tested by using the standard Wald test.

Following the verification of a long-term relationship, the dynamic multiplier effect is evaluated. The asymmetric cumulative dynamic multipliers' impacts on CO2E resulting from a single unit change in $GOEX_t^{+}$, $GOEX_t^{-}$, FDI_t^{+}, and FDI_t^{-} and can be determined using the following methods:

$$m_h^{+} = \sum_{j=0}^{h} \frac{\delta CO2_{t+j}}{\delta GOEX_{t-1}^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\delta CO2_{t+j}}{\delta GOEX_{t-1}^{-}}, \quad m_h^{+} = \sum_{j=0}^{h} \frac{\delta CO2_{t+j}}{\delta FDI_{t-1}^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\delta CO2_{t+j}}{\delta FDI_{t-1}^{-}}, h = 0,1,2 \ldots \quad (9)$$

where: as $h \rightarrow \infty$, then $m_h^{+} \rightarrow \beta_1^{+}$ and $m_h^{-} \rightarrow \beta_1^{-}$ for GOEX together with $m_h^{+} \rightarrow \beta_3^{+}$ and $m_h^{-} \rightarrow \beta_4^{-}$ for FDI. One should note that $\beta_1^{+} = \frac{\sigma_k^{+}}{\theta_k}$, $\beta_2^{-} = \frac{\tau_k^{-}}{\theta_k}$, $\beta_3^{+} = \frac{\cap_k^{+}}{\theta_k}$, and $\beta_4^{-} = \frac{\emptyset_k^{-}}{\theta_k}$. The calculated dynamic multipliers allow for the observation of system-impacting shocks, revealing the dynamic process of adjustment both towards and away from a new equilibrium state.

Table 2 shows the descriptive statistics that evaluate the performance of the underlying variables during the study period of 1990-2022, focusing on their central tendencies and dispersion. GOEX exhibited the highest mean value, followed by CO2E, GDPPC, TRADE, CREDIT, and FDI. Negative skewness is observed for all variables, except FDI and GOEX. The 33 observations in each series demonstrated a normal distribution. As indicated by the standard deviation, CO2E shows the highest volatility, followed by CREDIT, GOEX, GDPPC, FDI, and TRADE. This indicated a significant level of variability among the examined variables.

Table 2. Desciptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.
CO2E	11.427	11.460	13.027	9.869	0.943	-0.074	1.912	1.657	0.437
TRADE	4.778	4.830	5.229	4.193	0.293	-0.515	2.290	2.151	0.341
CREDIT	3.900	4.180	4.836	2.500	0.774	-0.527	1.759	3.646	0.162
FDI	1.631	1.569	2.480	1.023	0.352	0.792	2.768	3.520	0.172
GOEX	23.376	23.323	24.245	22.561	0.561	0.125	1.539	3.020	0.221
GDPPC	7.390	7.417	8.205	6.512	0.514	-0.089	1.824	1.945	0.378

4. Results and Discussion

4.1. Preliminary Analysis

This study examines the uneven impacts of fiscal policy tools and foreign direct investment inflows on environmental conditions in Vietnam. Table 3 presents the results of ADF and PP tests. The statistical findings from these tests reveal that all the variables exhibit stationarity at either I(0) or I(1), with no variables showing stationarity at I(2).

Table 3. Unit root test.

Variables	ADF (p-value)				PP (p-value)			
	Intercept		Intercept & trend		Intercept		Intercept & trend	
Level								
CO2E	0.078	0.959	-2.114	0.519	0.110	0.962	-2.228	0.459
TRADE	-0.683	0.837	-2.270	0.437	-0.497	0.879	-2.231	0.457
CREDIT	-1.706	0.419	-0.961	0.936	-1.706	0.419	-1.023	0.926
FDI	-3.057**	0.041	-3.342*	0.078	-2.807*	0.069	-2.969	0.156
GOEX	0.324	0.976	-3.763**	0.036	0.194	0.968	-1.814	0.674
GDPPC	-1.330	0.602	-3.758**	0.034	-2.257	0.192	-1.280	0.875
First differences								
CO2E	-5.501***	0.000	-5.395***	0.001	-5.542***	0.000	-5.429***	0.001
TRADE	-7.665***	0.000	-7.522***	0.000	-7.510***	0.000	-7.523***	0.000
CREDIT	-4.800***	0.001	-5.036***	0.002	-4.794***	0.001	-5.036***	0.002
FDI	-4.204***	0.003	-4.129**	0.014	-4.099***	0.003	-4.007**	0.019
GOEX	-4.424***	0.001	-4.364***	0.008	-4.507***	0.001	-4.456***	0.007
GDPPC	-4.887***	0.000	-5.026***	0.002	-3.671**	0.010	-4.181**	0.013

Note: *, **, and *** indicate significance at the 1 %, 5 %, and 10% levels, respectively.

Before employing the NARDL model, it was essential to examine the dataset for nonlinearity. To accomplish this, the nonlinear method known as BDS, introduced by Broock, Scheinkman, Dechert and LeBaron [77], was applied. Table 4 presents the results of the BDS test, indicating that all the variables exhibit nonlinear characteristics. Consequently, the NARDL model was deemed appropriate for further analysis.

Table 4. BDS test for nonlinearity results.

Series	Dimension 2	Dimension 3	Dimension 4	Dimension 5	Dimension 6
CO2E	0.195***	0.327***	0.423***	0.488***	0.540***
TRADE	0.161***	0.285***	0.384***	0.456***	0.505***
CREDIT	0.202***	0.339***	0.433***	0.495***	0.535***
FDI	0.103***	0.160***	0.181***	0.200***	0.206***
GOEX	0.191***	0.317***	0.399***	0.454***	0.491***
GDPPC	0.199***	0.336***	0.431***	0.499***	0.549***

Note: * indicates significance at the 1% level.

4.2. Results of NARDL Bound Test

To establish long-term connections between variables, this study employs a NARDL-bound methodology. The results of the NARDL-bound cointegration test are presented in Table 5. The findings reveal that the calculated F-statistics are significant at the 5% level, confirming the existence of a long-term co-integration relationship among the examined variables. This study distinguishes itself from previous research by demonstrating a long-run cointegration link between fiscal policy tools and CO2 emissions, within a nonlinear framework.

Table 5. NARDL bound test.

F-Bounds Test		**Null Hypothesis: No levels relationship**		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.90**	10%	2.03	3.13
k	7	5%	2.32	3.50
		2.50%	2.60	3.84
		1%	2.96	4.26

Note: ** indicates significance at the 5% level.

4.3. Long-Run Results

Another method to determine the existence of a long-term relationship is to examine the value of the cointegrating equation ECT_{t-1} [78] among the variables under study. The error correction term (ECT_{t-1}) coefficient is both negative and statistically significant, indicating a substantial convergence towards long-term equilibrium. Consequently, any deviation from the long-term equilibrium among variables is corrected in each time period, ultimately resulting in the restoration of a stable, long-term equilibrium state.

Table 6 presents the results for the asymmetric ARDL model. Long-term findings reveal that a positive change in FDI has a significant effect on CO2 emissions. Specifically, a positive shock of 1% in FDI leads to a 0.124% improvement in the environmental quality. While a negative shift in FDI shows an unfavorable impact on environmental quality through an increase in carbon emissions, this effect is not statistically significant. Foreign direct investment has played a crucial role in improving environmental quality and reducing carbon emissions in Vietnam through several channels. Multinational electronics and semiconductor companies have introduced advanced energy-efficient technologies to their manufacturing plants in Vietnam, contributing to cleaner production processes and reduced emissions [79]. Global apparel and footwear brands have imposed stricter environmental standards on their suppliers, prompting local firms to adopt sustainable practices [80]. For example, in the first 9 months of 2024, FDI into Vietnam reached 24.8 billion USD, led by high-value industries such as electronics, auto components, semiconductors and green technology [81]. Furthermore, foreign investors in the renewable energy sector have increased environmental awareness and invested in wind farms and solar power plants, contributing to Vietnam's transition towards a greener energy mix *[82,83*]. These outcomes agree with [84], who argue that in the long run, a positive shock in FDI inflows has a harmful and substantial effect on CO2 emissions in Nigeria, indicating that such a shock impedes CO2 emissions. The research conducted by [85] aligns with our results, indicating that in the immediate aftermath, a 1% rise in FDI correlates with a slight 0.015% decrease in energy transformation quality, suggesting initial negative environmental consequences. Nevertheless, over an extended period, a significant 0.042% enhancement in energy transformation quality implies that FDI-driven projects ultimately positively contribute to sustainable energy practices.

Table 6. NARDL coefficient estimates.

Long run estimation				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
FDI^{+}	-0.124***	0.029	-4.294	0.005
FDI^{-}	-0.125	0.088	-1.418	0.206

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$GOEX^+$	-1.275**	0.354	-3.604	0.011
$GOEX^-$	5.627**	2.022	2.783	0.032
TRADE	-0.487**	0.162	-3.009	0.024
CREDIT	0.357**	0.112	3.188	0.019
GDPPC	3.197***	0.362	8.823	0.000
Short-run estimation				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\Delta(FDI^+)$	-0.128**	0.041	-3.158	0.020
$\Delta(FDI^-)$	0.018	0.070	0.259	0.804
$\Delta(GOEX^+)$	-0.719**	0.273	-2.632	0.039
$\Delta(GOEX^-)$	7.678***	1.164	6.597	0.001
Δ (TRADE)	-0.608***	0.113	-5.358	0.002
Δ (CREDIT)	0.491***	0.106	4.648	0.004
Δ (GDPPC)	1.209*	0.494	2.446	0.050
C	-23.875***	3.378	-7.068	0.000
ECM(-1)	-2.456***	0.347	-7.088	0.000
R-squared	0.882	Adjusted R-squared	0.736	
F-statistic	6.054	Prob(F-statistic)	0.001	

Note: *,**, and *** indicate significance at the 1 %, 5 %, and 10% levels, respectively.

The current study deviates from the findings of Minh, et al. [86], who demonstrate that a 1% surge in FDI results in a 0.1% increase in CO2 emissions per capita. This divergence can be attributed to our research employing positive shocks in FDI as a factor positively affecting CO2 emissions. According to our analysis, positive shocks in foreign direct investment (FDI) can potentially decrease CO2 emissions in Vietnam. This may be due to the fact that when multinational corporations with advanced green technologies invest in Vietnam, they often introduce their environmentally-friendly production processes and cleaner technologies. This technology transfer can enable Vietnamese firms to adopt more energy-efficient and low-carbon practices, reducing their carbon footprint. For instance, Samsung's investment in Vietnam has facilitated the transfer of energy-efficient technologies in its manufacturing facilities, which has contributed to reducing emissions [87]. Furthermore, increased FDI in renewable energy projects, such as solar and wind farms, can directly contribute to reducing Vietnam's reliance on fossil fuels and decreasing CO2 emissions from the power sector. For example, the Bac Lieu wind farm, a joint venture between Vietnamese goverment and Philippines-based companies, has helped to reduce CO2 emissions by generating clean electricity [88].

The long-term effects of changes in government spending show that any positive shock on GOEX leads to lower emissions, whereas any negative shock on GOEX causes higher emissions. Specifically, a 1% increase in government expenditure results in a 1.275% reduction in pollution, whereas a 1% decrease leads to a 5.627% increase. This contrasts with previous studies by [22] and [10], and [11], which indicated that higher government spending harms environmental quality. In Vietnam, recent substantial growth in government operational expenses, outpacing revenue growth primarily driven by expanded social welfare programs, higher wages and benefits, and increased debt interest payments, explains the findings. The wage component now constitutes about 20% of the total expenditure, mostly because the base salary increases. Investments in education and healthcare have grown significantly, outpacing the average expenditure increase and raising their budget shares to 19% and 9.5%, respectively [89]. This aligns with [6], who argued that changes in spending on public goods can significantly reduce pollution levels. As a typical case, Japan's economy benefits from increasing government expenditure, leading to a 0.352% reduction in CO2 emissions [10]. The

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Japanese government is likely to focus on investments in economic projects employing advanced eco-friendly technologies, thus reducing pollution. This indicates that Japanese spending is mainly on human capital activities such as health and education, which generate lower carbon emissions than physical infrastructure. This supports the notion that, while consumption-driven expenditures can cause environmental pollution, spending on health and education may prompt the government to enhance environmental quality through income-related channels *[6,7*]. These findings imply that fiscal policies are effective tools to improve environmental quality and address climate change in Vietnam.

A negative shock in fiscal policy, characterized by a reduction in government spending, can lead to higher emissions in Vietnam for several reasons. First, a contraction in government expenditure may result in lower investments in environment-friendly infrastructure, renewable energy projects, and energy-efficient technologies. Foreign direct investment has played a crucial role in the development of Vietnam's renewable energy sector, particularly in wind and solar power projects, which could discourage such investments, hindering the transition towards a greener energy mix and leading to higher reliance on fossil fuels, which are major contributors to emissions *[82,90*]. Second, cuts in public spending on education and healthcare could adversely affect environmental quality [91]. As noted by [89], investments in these sectors have grown significantly in Vietnam, raising their budget shares, with education promoting environmental awareness and healthcare expenditure improving overall well-being and potentially reducing the harmful effects of pollution. A negative fiscal shock might undermine these investments, consequently weakening the government's ability to effectively address environmental concerns. Furthermore, a fiscal contraction could slow economic growth and reduce household incomes, potentially leading to greater reliance on less expensive but more polluting energy sources [92], such as coal or biomass, which is particularly relevant in Vietnam, where a significant portion of the population still relies on traditional energy sources [83].

The long-term findings suggest that TRADE coefficients have a considerable negative effect on carbon dioxide emissions. This indicates that a 1% shift in the TRADE coefficient results in an approximately 0.487% enhancement in the environmental quality. This result suggests that trade liberalization could play a crucial role in enhancing energy efficiency and promoting energy-saving technologies, thereby reducing the emission of pollutants such as CO_2 [93]. The estimated long-term coefficient of CREDIT is positive and statistically significant at the 5% level, suggesting that a 1% growth in economic activity leads to a 0.357% rise in CO_2 emissions. This observation indicates that economic expansion contributes to environmental deterioration over time. This suggests that financial development enables the provision of credit for energy-intensive goods, such as homes, automobiles, and appliances, which increases energy usage and carbon emissions [52]. Moreover, economic growth has a positive impact on CO_2 emissions, with a 1% increase in GDPPC resulting in a 3.197% decline in environmental quality. The increase in CO_2 emissions from economic growth is primarily attributed to increased energy consumption, industrialization, and urbanization. As economies grow, they tend to rely more heavily on fossil fuels for energy, releasing substantial amounts of CO_2. Research has demonstrated that the increased industrial activity and urbanization accompanying economic growth also contribute to higher emissions due to greater energy and transportation demands [68,94,95].

4.4. Short-Run Findings

As reported in Table 6, a 1% increase in foreign direct investment (FDI) leads to a 0.128% decrease in CO_2 emissions in the short term, while negative changes in FDI show no significant impact on environmental quality. Additionally, positive shifts in government expenditure (GOEX) demonstrated significant decreasing effects on CO_2 emissions, whereas a negative shift in government expenditure can lead to environmental degradation. Specifically, a 1% positive shock in the partial sum of government expenditures decreases carbon emissions by 0.719%, whereas a 1% negative shock increases emissions by 7.678%. Trade openness (TRADE) has a negative and significant effect on CO_2 emissions, with a 1%

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increase in trade openness improving environmental quality by 0.608%. Financial development (CREDIT) has a positive and significant impact on CO2 emissions, as a 1% increase in this factor increases CO2 emission levels by 0.491%. Economic growth (GDP) significantly contributes to increased CO2 emissions in the short run, with a 1% rise in GDP resulting in a 1.209% decline in environmental quality. Therefore, these short-term asymmetric responses persist in the long term. The nature of the linkages persists consistently in both the short and the long run.

4.5. Stability Diagnostic Test

The research conducted various diagnostic assessments to evaluate NARDL outcomes, with comprehensive results presented in Table 7. The Breusch–Godfrey LM test was employed to detect serial correlation among variables. The table indicates that the LM test shows no first-order serial correlations. The RESET test confirmed the absence of model misspecification issues. Heteroscedasticity was examined using the Breusch-Pagan-Godfrey test and ARCH test, with insignificant probability F-statistic values, suggesting that the null hypothesis of homoscedasticity cannot be rejected. The Jarque-Bera test for normal distribution demonstrates that the variables follow a normal distribution. Finally, the Wald test was used to examine the nonlinear behavior of the model. The Wald test results indicate long-run asymmetries in the model for government expenditure.

Table 7. Results of diagnostic tests.

Diagnostic tests	F-statistic	P-value
Model misspecification: RESET test	0.376	0.566
Serial Correlation: Breusch-Godfrey LM test	3.340	0.140
Heteroskedasticity Test: Breusch-Pagan-Godfrey	0.486	0.902
Heteroskedasticity Test: ARCH	0.779	0.385
Normality test: Jarque-Bera test	2.147	0.342
Long-run asymmetries based on Wald test	F-statistics	Prob.
FDI	0.552	0.486
GOEX	5.053*	0.066
Short-run asymmetries based on Wald test	F-statistics	Prob.
FDI	0.663	0.425
GOEX	1.327	0.262

Note: * indicates a 10% significance level.

Stability techniques were used to evaluate the structural stability of the model. Figure 1 illustrates the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests, as introduced by [96]. The results demonstrate that the statistics are significant at the 5% level, indicating that the model coefficients are structurally stable.

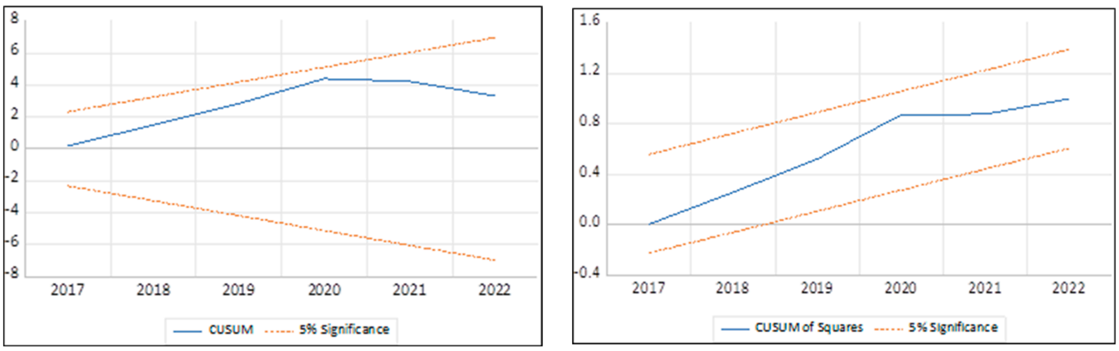

Figure 1. Plots Cumulative sum and cumulative sum of squares.

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Figure 2 illustrates the dynamic multiplier plots used to evaluate the asymmetries resulting from separating GOEX and FDI into positive and negative shocks. The findings indicate an asymmetric adjustment of government expenditure (GOEX) and foreign direct investment inflows (FDI) towards equilibrium in response to positive and negative shocks over the long term. Additionally, an expansionary fiscal policy leads to a reduction in CO2 emissions. Conversely, a contractionary fiscal policy results in a slight decrease in emissions during the forecast period.

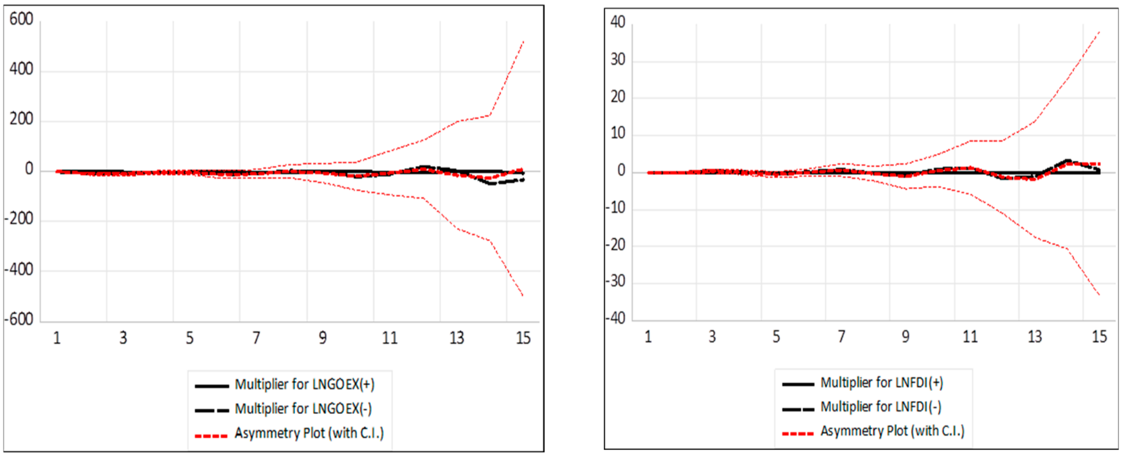

Figure 2. Dynamic multiplier graphs of GOEX and FDI.

Notes: The solid black line indicates positive shocks to the GOEX and FDI, while the dashed black line indicates negative shocks. The red dashed lines illustrate the dynamic multiplier combinations resulting from the positive and negative shocks of the disaggregated GOEX and FDI on CO2 emissions. The vertical axis shows the range of positive and negative impacts, and the horizontal axis shows the time frame.

5. Conclusion and Policy Implications

The impact of fiscal policy on environmental quality can be beneficial or harmful depending on public sector spending, causing asymmetric effects on CO2 emissions. Furthermore, mixed results have been found in previous studies on the decisive role of FDI. Based on this backdrop, this study examines the asymmetric influence of fiscal policy and FDI on Vietnam's environmental pollution (1990-2022) using the NARDL approach. The results indicate that the NARDL models statistically confirm a long-term causal relationship among variables, with a significant negative cointegrating parameter indicating both short-term dynamics and long-term equilibrium effects. Based on the asymmetric ARDL estimation, an analysis of the long-run impacts of alterations in government expenditure reveals that a positive shock in GOEX results in decreased emissions, whereas a negative disruption in GOEX leads to increased emissions. Increases in foreign direct investment (FDI) can significantly decrease CO2 emissions because FDI targets energy-saving industries and eco-friendly technologies. Conversely, decreases in FDI have a statistically insignificant effect on reducing CO2 emissions, indicating that an increase in pollution is not strongly linked to FDI decline. Trade openness enhances environmental quality, possibly by improving energy efficiency, while economic growth and financial development increase CO2 emissions because of higher energy consumption, industrialization, and urbanization.

Given these findings, Vietnam and other countries with identical economic backgrounds can adopt strategic measures to improve environmental quality by reducing carbon emissions. First, adapting fiscal policy is essential, with increased government investment in public goods such as healthcare and education, which have smaller carbon footprints than heavy industry, thus reducing emissions while fostering economic growth toward sustainability. Second, Vietnam should design policies to draw FDI into green technologies and low-energy sectors by offering incentives for clean

 doi:10.20944/preprints202501.1779.v1

energy initiatives and enforcing strict regulations for high-pollution industries. Third, enhancing trade openness can aid in acquiring eco-friendly technologies and adopting international energy efficiency standards by revising trade policies to favor low-carbon imports and exports. Fourth, financial development should prioritize green investments and sustainable financial mechanisms, including green bonds and sustainability-linked loans, to channel funds into emission-reducing projects. Finally, economic growth must shift towards green sectors, encouraging investments in clean energy and low-carbon technologies, thereby uncoupling the economic progress from energy consumption and CO2 emissions.

This analysis elucidates the asymmetric impacts of fiscal policy, FDI inflows, and other variables on CO2 emissions in Vietnam. Nonetheless, certain limitations must be considered in subsequent research. Extending the nonlinear ARDL approach to a panel of countries should improve the generalizability of the findings and facilitate cross-country comparisons, yielding more robust conclusions relevant to various economic structures and policy contexts. Furthermore, integrating disaggregated data at regional or sectoral levels may reveal potential heterogeneities within Vietnam, providing more nuanced insights and facilitating customized policy recommendations. Moreover, incorporating other explanatory variables, such as technical advancements, investments in renewable energy, and environmental regulations could yield a more thorough understanding of the factors affecting environmental quality. Expanding research to include additional environmental indicators beyond CO2 emissions, such as air pollution, water quality, and deforestation, would provide a comprehensive evaluation of environmental impacts, thereby guiding policymakers on a wider array of issues. Addressing these constraints could provide policymakers with more nuanced knowledge, facilitating the creation of effective, context-specific solutions to combat climate change, and advance sustainable development across diverse regions and industries.

Funding: This research was funded by University of Economics Ho Chi Minh City, Vietnam with grant number XXX.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

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

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