

The Nonlinear Effect of Environmental Taxes on Carbon Emissions in Kenya, Uganda, and Rwanda

Diphus Tugume

diphustugume@gmail.com

International Growth Centre

Research Article

Keywords: Environmental tax, carbon dioxide emissions, STIRPAT model, Kenya, Uganda, Rwanda, panel data, climate policy

Posted Date: July 23rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10120932/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

The Nonlinear Effect of Environmental Taxes on Carbon Emissions in Kenya, Uganda, and Rwanda

Diphus Tugume¹

¹Diphus Tugume, Research Fellow, International Growth Centre, Kampala, Uganda.

Email: diphustugume@gmail.com

Abstract

The study examined whether environmental taxes reduce carbon dioxide emissions in Kenya, Uganda and Rwanda during 2001–2022. Sub-Saharan Africa is highly vulnerable to climate change, and East Africa's emissions have risen as growth, industrialisation and transport expansion increased reliance on fossil fuels. Pigouvian theory implies that taxes internalise pollution costs, but their effectiveness depends on the tax structure. Using STIRPAT-based static panel models with OECD and World Bank data, total and disaggregated environmental taxes were analysed alongside GDP per capita, energy intensity and urbanisation as the control variables. The panel covers only three countries across a 22-year span. The results revealed nonlinear effects: total, energy, and transport taxes reduce emissions up to turning points near 3.45%, 2.1–2.4%, and 0.75–0.88% of GDP, respectively. Pollution taxes are ineffective until revenues exceed roughly 0.024–0.097 % of GDP. Higher income, energy intensity and urbanisation were found to raise carbon emissions. Energy taxes comprise the largest share of environmental taxes, and Kenya has the highest tax share and CO₂ emissions. The study concludes that well-designed taxes can mitigate emissions but only up to category-specific thresholds; beyond these thresholds, additional taxes yield diminishing or counterproductive effects. Thus, policymakers should consider specific environmental taxes rather than treating them as a whole.

Keywords: Environmental tax; carbon dioxide emissions; STIRPAT model; Kenya; Uganda; Rwanda; panel data; climate policy.

JEL: Q54; Q58; H23; C23; O55.

1. Introduction

Environmental taxation is grounded in corrective-tax theory, which recommends taxing pollution so that firms and households internalise environmental costs (Polinsky & Shavell, 1982). Sub-Saharan Africa is highly vulnerable to climate change because extreme heat, shifting rainfall patterns, floods and prolonged droughts directly harm health and livelihoods, and these stresses are intensified by socioeconomic vulnerabilities and insufficient supportive policies (Connolly-Boutin & Smit, 2016; Serdeczny et al., 2017). In East Africa, carbon dioxide (CO₂) emissions show a two-stage exponential growth pattern driven by economic and population growth, industrialisation, and transport development; while technical progress in hydropower and geothermal energy exists, emissions continue to rise due to a growing reliance on oil and coal (Sun et al., 2022). Such rapid emissions growth illustrates the difficulty of sustaining development while reducing carbon output in Kenya, Uganda and Rwanda.

Studies conducted in developed countries have indicated that well-designed environmental taxes can help reduce emissions. The case of Sweden shows that after the introduction of a carbon tax on transport fuels, there was nearly an 11% reduction in CO₂ emissions by the transport sector, and the elasticity of the tax was higher than that of the price for the demand for gasoline (Andersson, 2019). In addition, in the Group Seven (G7) countries, a significant increase in environmental taxes resulted in a massive reduction in carbon emissions (Doğan et al., 2022). Additionally, empirical evidence collected from the seven developing nations indicates that there is a negative relationship between the total environmental taxes and carbon emissions, and there is causation from taxes to carbon emissions (Wolde-Rufael & Mulat-Weldemeskel, 2021).

Although environmental taxation can correctively curb carbon emissions, outcomes depend on tax design, tax levels and country context (Al Shammre et al., 2023; Ulucak et al., 2020). Aggregate environmental-tax measures may hide different effects because energy, pollution and transport taxes operate through distinct bases and price channels, and research on emerging economies finds that total and energy taxes influence emissions (Wolde-Rufael & Mulat-Weldemeskel, 2021). Non-linear evidence further complicates policy design: one study using a panel smooth transition regression finds that environmental taxation reduces CO₂ emissions only above certain levels of economic integration and that related technologies and patents become effective only at higher levels of globalisation (Ulucak et al., 2020). Another dynamic panel threshold analysis for OECD countries shows that total environmental, energy and

pollution taxes reduce CO₂ emissions only once specified tax thresholds are exceeded (Al Shammre et al., 2023). Given differences in tax structures, energy systems, and development constraints, it was uncertain whether results from OECD or broader emerging-economy panels would apply to Kenya, Uganda, and Rwanda.

Hence, this paper examined the disaggregated effect of environmental taxation on per-capita CO₂ emissions in Kenya, Uganda and Rwanda over 2001–2022. The analysis considered total environmental taxes and three categories—energy taxes, pollution taxes and transport taxes—to determine whether their emissions-reducing effects differ by category, and tests for non-linear tax effects because evidence suggests that taxes may only reduce emissions above threshold levels. By controlling for income, urbanisation and energy intensity, the study isolated fiscal effects from structural drivers of emissions. The current study contributes to the literature by showing whether environmental taxes reduce CO₂ emissions, whether effects vary by tax category, and whether there exist thresholds at which effects diminish.

The remainder of the paper is organised as follows: Section 2 reviews theoretical and empirical work on environmental taxation and carbon-emissions reduction; Section 3 describes the data and empirical strategy; Section 4 presents and discusses the results; and Section 5 concludes with policy implications and suggestions for future research.

2. Literature Review

Environmental taxes have increasingly become a weapon in the battle to mitigate climate change and environmental degradation. The study was based on two theories: the Pigouvian Tax and the Green Paradox. Environmental taxes can be grounded in the Pigouvian theory, first postulated by economist Pigou and later refined by Polinsky and Shavell (1982). According to this theory, taxes serve as a corrective measure for the differences between private and social costs arising from externalities (Pigou, 2017). From this perspective, people are affected by negative externalities arising from climate change, including elevated CO₂ levels from pollution (Roach et al., 2019). Imposing environmental taxes can therefore help to reduce CO₂ emissions for the greater good (Al Shammre et al., 2023; Guo & Wang, 2018).

In contrast, the Green Paradox hypothesis highlights potential unintended consequences. According to Sinn (2015), the hint of government intervention in future environmental taxes may prompt resource owners to extract their fossil fuel stocks more quickly due to expected tighter controls. Such a supply-side response can worsen short-term emissions, indicating the key role of policy timing and credibility. (Ulucak et al., 2020; Wolde-Rufael & Mulat-Weldemeskel, 2021). Empirical evidence indicates that once the expectation of environmental tax implementation is raised, fossil fuel production increases in the OECD and BRICS nations (Aydin & Esen, 2018; Esen et al., 2021; Zaghdoudi & Maktouf, 2017).

There has been an emergence of empirical studies that complement and supplement theories explaining how environmental taxes affect greenhouse gas emissions and environmental degradation, with a growing body of evidence confirming their effectiveness in reducing carbon emissions. Doğan et al. (2022) demonstrate that environmental taxes significantly reduce CO₂ emissions across G7 economies using panel cointegration and FMOLS methods, while Xie and Jamaani (2022) show, through quantile regression, that higher environmental taxes are consistently associated with lower CO₂ emissions, particularly at higher pollution levels. Scholars have continued the discussion past a handful of boundaries. Environmental taxes have a significant effect in reducing carbon emissions in E7 nations. (Tao et al., 2021). Additionally, Sarpong et al. (2023) align with the COP-26 agenda, supporting the view that environmental taxation is a positive factor in reducing CO₂ emissions. Focusing on the empirical evidence conducted on particular nations, the situation is a more mixed bag, with Telatar and Birinci (2022) discovering little effect of environmental taxes on CO₂ emissions in Turkey, while Akkaya and Hepsag (2021) found a null effect of fuel taxes on CO₂ emissions

in Turkey, both in the short- and long-run. According to Ocansey and Haywood-Dadzie (2025), a total of 105 research works were evaluated from 2014 to 2024, and it was revealed that environmental taxes are effective measures to mitigate CO₂ emissions, although this depends on the tax system. On the whole, extensive research has established that CO₂ emissions decrease with the use of environmental taxes; hence, the formulation of hypothesis one: Higher environmental taxes reduce CO₂ emissions.

Another line of studies finds that the effectiveness of environmental taxes depends more on the type of tax rather than on the overall level of environmental taxes. For instance, Meireles et al. (2021) find that transport taxes, that is, car registry taxes, decrease CO₂ emissions in the Mediterranean regions in the long run. Wolde-Rufael and Mulat-Weldemeskel (2021) find that CO₂ emissions decrease as the amount of total taxes on the environment, energy, and transport increases. In opposition, Akkaya and Hepsag (2021) find that fuel taxes, implemented in Turkey, had little effect, while transport taxes led to more sustainability in the long run, as stated by Ahmad and Satrovic (2023). This has informed the formulation of the second hypothesis of the study: the effect of environmental taxes differs by tax category: energy, pollution, and transport taxes.

Recent literature has increasingly focused on nonlinearities and threshold effects, suggesting that carefully designed environmental taxes will not hamper production and consumption. For instance, it is clear from Zaghdoudi and Maktouf (2017) that in OECD countries, reductions in CO₂ emissions occur only once a critical threshold tax rate is exceeded. Ulucak et al. (2020) report similar nonlinear patterns across the BRICS, noting that overly low tax rates could trigger the Green Paradox and worsen outcomes. Esen et al. (2021) showed that a tax in the EU-15 nations tends to shrink ecological deficits when exceeding specific thresholds. The latest research, such as that by Al Shammre et al. (2023), identifies specific thresholds for the level of taxation within OECD economies: 3.002% of GDP for total environmental taxes, 1.991% for energy taxes, and 0.377% for pollution taxes. Domguia et al. (2024) support the growing impact of decarbonization in the industry and transport sectors when the tax-intensity threshold is crossed. Henceforth, the study adopted the third hypothesis: the relationship between environmental taxes and CO₂ emissions is nonlinear, with a turning point or threshold.

According to the existing literature on environmental taxes and CO₂ emissions, three gaps require further investigation. First, most studies investigate the effect of aggregate environmental taxes and provide a very narrow insight into how each category- energy taxes,

pollution taxes, and transport taxes- affects CO2 emissions. Second, several studies have focused on linear effects, overlooking nonlinear patterns that may affect the effectiveness of these taxes. Lastly, significant knowledge gaps exist in developing countries. For instance, Africa and other developing regions receive very little representation, as most studies are conducted in developed countries. This study bridges these gaps by providing evidence from Kenya, Rwanda, and Uganda.

3. Methodology

The analysis was guided by the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework. This model has its roots in the IPAT identity first introduced by Ehrlich and Holdren (1971) and was later advanced by Dietz and Rosa (1997) to allow hypothesis testing and flexible elasticities, overcoming the deterministic limits of the IPAT identity. The STIRPAT model has now become a common framework for examining how environmental impacts are related to their underlying drivers (Al Shammre et al., 2023; Domguia et al., 2024; Ulucak et al., 2020). In its general form, the STIRPAT model can be expressed as:

$$I_{it} = \alpha P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3} \varepsilon_t, \quad (1)$$

where I_{it} denotes environmental impact, P represents population, A captures affluence, T denotes technology, and ε_t captures the error term. Taking natural logarithms yields the estimable log-linear form of equation (1):

$$\ln I_{it} = \alpha + \beta_1 \ln P_t + \beta_2 \ln A_t + \beta_3 \ln T_t + \varepsilon_t, \quad (2)$$

Following Chen et al. (2022) and Mehta and Derbeneva (2024), environmental impact was measured by carbon dioxide emissions per capita (CO2_pc); real GDP per capita (GDP_pc) was used as a proxy for affluence; urban population was used as a proxy for population (urb_share); and, lastly, energy intensity was used to represent technology (energy_int). Since the main objective of the study was to examine the role of fiscal policy on environmental impact, the study augmented equation (2) to add environmental taxation variables. Henceforth, environmental taxes capture policy-induced price signals affecting CO2 emissions (Mpofu, 2022; World Bank, 2022). This gives an extended empirical specification as:

$$co2_pc_{it} = \alpha + \beta_1 gdp_pc_{it} + \beta_2 energy_int_{it} + \beta_3 urb_share_{it} + \beta_4 tax_{it} + \varepsilon_{it}, \quad (3)$$

where tax_{it} represents environmental taxes. The study followed a panel data econometric model specification where i refers to the country and t refers to the time period. From the

Pigouvian theoretical perspective, β_4 was expected to be negative. This is because environmental taxes introduce an extra cost, reflected in a higher price, which changes consumption and production behaviour, leading to reduced CO2 emissions.

Following growing empirical concern that environmental taxes have a nonlinear relationship with CO2 emissions (Al Shammre et al., 2023; Ulucak et al., 2020). Equation (3) was further extended to include a quadratic term by squaring the environmental taxes. Therefore, the quadratic specification can be written as:

$$co2_pc_{it} = \alpha + \beta_1 gdp_pc_{it} + \beta_2 energy_int_{it} + \beta_3 urb_share_{it} + \beta_4 tax_{it} + \beta_5 tax_{it}^2 + \varepsilon_{it}, \quad (4)$$

tax_{it}^2 allows the marginal effect of environmental taxation to vary with the level of taxation, and the marginal effect can be obtained by differentiating equation (4) with respect to the environmental tax. Thus, differentiating equation (4) with respect to the environmental tax leads to:

$$\frac{\partial co2_pc_{it}}{\partial tax_{it}} = \beta_4 + 2\beta_5 tax_{it} \quad (5)$$

Setting equation (5) to zero yields the turning point, which can be expressed as follows:

$$tax^* = -\frac{\beta_4}{2\beta_5}, \quad (6)$$

tax^* represents the threshold at which environmental taxation is predicted to reach its turning point, holding other factors constant. The nature of the tax–emissions relationship depends on the signs of β_4 and β_5 . When $\beta_4 < 0$ and $\beta_5 > 0$, the relationship is U-shaped. In this case, increases in environmental taxation are associated with declining emissions up to the threshold tax^* , after which further increases are associated with diminishing effectiveness of environmental taxes in reducing emissions. Conversely, when $\beta_4 > 0$ and $\beta_5 < 0$, the relationship is inverted U-shaped. In the second case, increasing environmental taxation is associated with an initial increase in emissions up to the threshold tax^* , after which further increases are associated with increasing effectiveness of environmental taxes in reducing emissions. If both coefficients are positive, the relationship is monotonically increasing; if both are negative, it is monotonically decreasing. Where both coefficients are zero, no systematic relationship is identified.

Consistent with Ewane and Ewane (2023) and Adeleye et al. (2023). A meaningful turning point requires that the linear and quadratic terms have opposite signs. For the emissions-

minimising threshold to be empirically valid, three conditions must be satisfied: (i) both β_4 and β_5 must be statistically significant; (ii) $\beta_5 > 0$ to ensure convexity and the existence of a minimum; and (iii) the estimated tax^* must lie within the observed sample range. Under these conditions, tax^* characterises a data-consistent threshold in the long-run relationship between environmental taxation and per-capita carbon emissions.

Following the study's second hypothesis and to capture heterogeneity across categories, the analysis estimated separate models for each environmental tax category: total environmental taxes (*env_tax*), energy taxes (*ener_tax*), transport taxes (*tra_tax*), and pollution taxes (*pol_tax*). Each tax variable was entered individually in both linear and quadratic forms to avoid multicollinearity and to isolate category-specific effects.

Based on economic theory and the STIRPAT framework, the coefficient β_1 was expected to be positive, indicating that rising per capita income leads to greater consumption, more industries, and increased resource extraction, resulting in higher CO2 emissions. The coefficient β_2 was also expected to be positive, since higher energy use per unit of output implies greater fossil fuel dependence and higher CO2 emissions. The coefficient β_3 was expected to be positive because, as urbanisation advances, it can increase CO2 emissions through higher energy consumption, increased industrial activity, transportation, and construction of necessary infrastructure. The coefficient β_4 was expected to be negative, while β_5 was expected to be positive if diminishing returns or threshold effects are present (see equation 4). The study used publicly available data from the Organisation for Economic Co-operation and Development (OECD) and the World Bank's World Development Indicators (WDI) websites. The data covered the period from 2001 to 2022 to form a country-year panel. The names of the variables, their abbreviation, and sources are summarised in Table 1.

Table 1 Description and sources of variables

Abbreviation	Variable Description	Source
co2_pc	CO2 emissions (metric tons) per person	WDI
env_tax	Total environmental tax revenue (%GDP)	OECD
energy_tax	Energy tax revenue (%GDP)	OECD
Pol_tax	Pollution tax revenue (%GDP)	OECD
trans_tax	Transport tax revenue (%GDP)	OECD
energy_int	Energy intensity level of primary energy (MJ/\$2021 PPP GDP)	WDI
gdp_pc	GDP per capita (constant 2015 US\$)	WDI
urb_share	Urban population (% of total population)	WDI

Source: Authors' computation

Following Sohag et al. (2018), when dealing with panel data, selecting a suitable model depends on the number of cross-sections (N) and the number of years (T). This study adopted static panel models since $N < 25$ and $T < 25$. Further, for short panel time periods, the issue of stationarity becomes less important. In fact, according to Harris and Tzavalis (1999) and Tzavalis (2002), when T is small, conventional unit root tests have lower statistical power and often yield incorrect results. Hence, it is not advisable to perform unit root tests when T is small; henceforth, the current study did not conduct unit root testing.

4. Results and Discussion

4.1 Descriptive Statistics

The descriptive statistics were summarised in Table 2 and underscore the differences in fiscal approaches to environmental management across Kenya, Uganda and Rwanda. The average level of total environmental taxes across the three countries is 1.8% of their GDP, ranging from 0.53% to 3.76% over 2001 to 2022. Energy taxes are the largest contributors to total environmental taxes, averaging 1.23% of GDP; transport taxes are the second-largest, averaging 0.55% of GDP; and pollution taxes are the third-largest, averaging 0.02% of GDP. In relation to the changes across the three countries, Kenya has the highest at 2.38% of GDP, followed by Uganda at 1.94% and Rwanda at 1.08%.

In addition, Kenya is the highest among the three countries in terms of GDP per capita and CO₂ emissions, followed by Uganda and then Rwanda. Additionally, Kenya has the highest energy taxes at 1.32% of GDP; Uganda has the highest transport taxes at 1.73% of GDP; Rwanda has the lowest in all categories; and Uganda has the highest pollution taxes at 0.07% of GDP. Kenya also leads in the percentage of people living in urban areas, with a mean of 29.6%, followed by Uganda at 20.68%, and lastly Rwanda at 19%.

Table 2 Descriptive Statistics

Stat	co2_ pc	Env_tax	Energy tax	Pollution tax	Transport tax	Energy int.	GDP pc	Urban share
Kenya								
N	22	22	22	22	22	21	22	22
Mean	0.32	2.38	1.32	0	1.06	5.23	1404.58	29.63
SD	0.06	0.68	0.62	0	0.16	0.25	179.83	3.55
Min	0.21	1.56	0.7	0	0.74	4.76	1169.14	20.44
Max	0.41	3.76	2.52	0	1.32	5.62	1747.53	31.87
Rwanda								
N	22	22	22	22	22	22	22	22
Mean	0.09	1.08	0.64	0	0.45	5.22	632.99	18.98
SD	0.02	0.3	0.2	0	0.12	1.12	179.21	3.4
Min	0.07	0.53	0.23	0	0.27	3.51	358.45	16.55
Max	0.16	1.54	0.98	0	0.67	7.19	948.41	27.78
Uganda								
N	22	22	22	22	22	22	22	22
Mean	0.12	1.94	1.73	0.07	0.15	10.87	768.45	20.67
SD	0.04	0.42	0.36	0.05	0.09	1.27	136.85	6.25
Min	0.06	1.39	1.24	0	0.07	9.52	519.46	11.9
Max	0.18	2.86	2.58	0.17	0.35	13.54	933.09	29.93
Total								
N	66	66	66	66	66	65	66	66
Mean	0.18	1.8	1.23	0.02	0.55	7.14	935.34	23.09
SD	0.11	0.73	0.62	0.04	0.4	2.87	376.52	6.53
Min	0.06	0.53	0.23	0	0.07	3.51	358.45	11.9
Max	0.41	3.76	2.58	0.17	1.32	13.54	1747.53	31.87

Source: Authors' computation

4.2 Multicollinearity Test

Following Gujarati (2009), VIF has been used to assess multicollinearity. The rule of thumb is that a mean VIF of 10 or higher raises concerns about multicollinearity. Furthermore, the study has applied the pairwise correlation method described by Gujarati (2002). A rule of thumb is that values above 0.80 in the pairwise correlation matrix indicate serious multicollinearity. Results are shown in Table 3. They provide the correlation matrix of environmental taxes and the control variables.

Total environmental tax was found to be positive and highly correlated with energy tax (0.86), transport tax (0.48), GDP per capita (0.47), and urban share (0.43). The energy tax was positively correlated with energy intensity (0.58) and urbanisation (0.63). Also, the pollution tax was positively correlated with energy intensity (0.61) but negatively correlated with the transport tax (−0.60). The transport tax was highly positively correlated with GDP per capita (0.77) but negatively correlated with energy intensity (−0.66). Also, GDP per capita was negatively correlated with the energy intensity (−0.41). Urban share was moderately correlated with the energy tax and pollution tax. Mean VIF was 4.32. Thus, multicollinearity was not considered a problem, as the VIFs were well below 10 and the correlations among the main independent variables were below 0.8.

4.3 Non-linear Relationship between Environmental Taxes and CO2 Emissions

In Figure 2, the LOWESS-smoothed graphs show the relationship between CO2 emissions and the four types of environmental taxes. The LOWESS curve was applied to test for a non-linear effect before introducing the threshold term into the model. In the first panel (I), the graph illustrates a non-linear association between the two variables: total environmental taxes negatively affect CO2 emissions once a threshold is reached. The second panel (II) shows a similar non-linear association, with emissions declining above the threshold. In the third panel (III), which considers transport taxes, the result is mixed; initially, it follows a similar pattern. However, panel (III) generally shows that transport taxes do not affect CO2 emissions, no matter the taxation level. In the fourth panel (IV) on pollution taxes, the trend is steady and similar, with pollution taxes influencing CO2 emissions after a certain threshold. Therefore, the graphs indicate non-linear relationships between environmental taxes and CO2 emissions, and that a threshold model is necessary to identify the fiscal threshold, or turning point. These findings align with those in OECD countries, where environmental taxes reduce CO2 emissions only after the lower threshold is reached, but they become inefficient after the upper threshold is attained (Al Shammre et al., 2023).

4.4 Environmental Taxes and Carbon Dioxide Emissions

The strategy used in the preceding section for estimating results was as follows: the study began by employing pooled OLS. Following this, model misspecification was tested using the Ramsey RESET Test (Ramsey, 1969). However, omitted-variable bias was found in the pooled OLS models. Subsequently, fixed and random effects were estimated, and the choice between them was based on the Hausman Test, which assesses violations of the orthogonality condition

underlying RE estimation (Hausman, 1978). After selecting the fixed effects estimation method, the study further followed the deviations from classical assumptions that were remedied through an additional step of estimation based on the fixed effects weighted least squares with Driscoll-Kraay standard errors to address heteroskedasticity, serial correlation, and cross-sectional dependence common to panel data (Driscoll & Kraay, 1998). To address endogeneity. To obtain long-run estimates, the study used the fully modified ordinary least squares estimator developed by Pedroni (2001) as a robustness check. The study presented in Tables 4 to 7 the Ramsey RESET test, which rejected the pooled OLS specification; the Hausman test results, which favoured FE over RE; and post-estimation diagnostics following FE estimation that indicated serial correlation and heteroskedasticity in the residuals. Despite the above, we adopted the weighted FE estimator with Driscoll–Kraay standard errors, which account for cross-sectional dependence, autocorrelation, endogeneity, and heteroscedasticity, in order to robustify the inference before interpreting the coefficient estimates (see column 4).

Based on the results in Table 4, the preferred weighted fixed-effects model indicates that the linear coefficient on total environmental tax revenue is -0.0280 and was statistically significant at the 5% level. This implies that a 1-percentage-point increase in total environmental tax revenue as a % of GDP was associated with a 0.028 metric ton decrease in per capita CO₂ emissions, holding GDP per capita, energy intensity, and urbanisation constant. In fully modified ordinary least squares (FMOLS), the linear term on total environmental tax revenue remains negative (-0.0415), and the squared term was positive and statistically significant (0.0060), implying a U-shaped relationship with an emission-minimising turning point around 3.45% of GDP. Substantively, this pattern suggests that increasing total environmental taxes was associated with emissions reductions of up to about 3.5% of GDP in the short and long run, after which the marginal effectiveness of total environmental taxes in reducing carbon emissions diminishes and may even reverse (see Table 4).

Energy and transport taxes exhibit nonlinear category patterns across estimators. For energy taxes, both weighted fixed effects and FMOLS report negative, highly significant linear coefficients (-0.0655 and -0.0696) and positive, significant quadratic coefficients (0.0154 and 0.0145), implying an emissions-minimising turning point between about 2.1% and 2.4% of GDP for the fixed-effects weighted least squares model (short run) and for the FMOLS model (long-run), respectively. These findings are consistent with a mechanism in which energy taxes directly shift relative fuel prices and induce efficiency improvements, but where additional increases beyond a defined threshold yield smaller incremental reductions and potentially

offsetting behavioural or structural responses (see Table 5). Transport taxes show a similar U-shape relationship, with turning points around 0.75% of GDP for the fixed-effects weighted least squares model (short-run) and 0.88% of GDP for the FMOLS model (short-run). This implies that transport-related taxation can be effective in reducing carbon dioxide emissions by discouraging fuel use and increasing vehicle-efficiency incentives up to the turning point at about 0.88%, where incremental transport taxes face diminishing marginal effectiveness. At this point, the effectiveness of transport taxes in reducing carbon emissions diminishes (see Table 6).

Based on the fixed-effects weighted least squares model results (short-run), the linear coefficient of pollution taxes was positive and significant (0.9187), while the quadratic term was negative and significant (-4.7263), implying an inverted-U relationship with a turning point approximating to 0.097% of GDP. The long-run results from the FMOLS model indicate that the turning point was around 0.024% of GDP. This implies that pollution-tax revenues initially correlate with higher CO₂ emissions; however, the square of pollution-tax revenues is associated with lower CO₂ emissions. This implies that pollution taxes in Kenya, Rwanda, and Uganda may be particularly sensitive to measurement errors, small tax bases, and low tax levels, hence making them unreliable for reducing CO₂ emissions (see Table 6).

The above findings are similar to threshold findings elsewhere. For instance, employing dynamic threshold models for the Organisation for Economic Co-operation and Development, Al Shammre et al. (2023) revealed that particular environmental taxes decrease CO₂ emissions after surpassing upper thresholds of approximately 3%, 1.99%, and 0.377% for the total environmental tax, energy tax, and pollution tax, respectively, indicating a weak effect at a low tax intensity level and a strong effect after a regime switch.

Based on the results in Tables 4 to 7, GDP per capita, urbanisation, and energy intensity had a positive, statistically significant effect on CO₂ emissions. This implied that, as expected, population, affluence, and technology are key determinants of environmental impact in the three countries as stipulated by the STIRPAT model (Dietz & Rosa, 1997; York et al., 2003). In this logic, income growth was likely to raise production and consumption levels, leading to increased energy demand, while energy intensity represents an economy's efficiency in using energy to produce output; thus, a higher energy intensity indicates a more carbon-intensive growth trajectory. Similarly, the positive association between urbanisation and CO₂ emissions is consistent with the view that urban transition, especially in rapidly transforming economies,

can elevate CO₂ emissions through infrastructure build-out, increased mobility demand, construction activity, and higher commercial and residential energy use. Although urban form can eventually generate efficiency gains via density and public transport, the empirical literature indicates that urbanisation often increases energy consumption and CO₂ emissions when planning, technology, and fuel mixes remain carbon-intensive (Liddle, 2014; Poumanyvong & Kaneko, 2010).

5. Conclusions and Policy Recommendations

The study was based solely on a three-country panel covering Kenya, Rwanda, and Uganda for the period 2001–2022. The main focus of the study was to examine whether environmental taxes reduce carbon emissions, whether their effects differ across tax categories, and whether there are clear thresholds beyond which the marginal effect of environmental taxes begins to diminish. Across the models, total environmental taxes, energy taxes, and transport taxes consistently showed a non-linear relationship with CO₂ emissions in which the linear tax term is negative, that is, a higher tax revenue share was associated with lower per-capita CO₂, while the squared term is positive, implying that the marginal effectiveness of these taxes weakens and can reverse if there is increased taxation pressure.

The results of the present study suggest that not all environmental taxes reduce CO₂ emissions, and their effectiveness remains a subject of academic debate. Pollution taxes were found to significantly reduce CO₂ emissions when the level of taxation is high, that is, after squaring them in both the short run and the long run. Thus, policymakers in Kenya, Uganda, and Rwanda cannot assume that any environmental tax will automatically reduce CO₂ emissions; rather, environmental taxation must be carefully calibrated at a disaggregated level to achieve emission-reduction goals and avoid one-size-fits-all approaches. The results also support the view that environmental taxes have a nonlinear relationship with per-capita CO₂ emissions, and that their effect depends on the tax category under consideration. Specifically, the turning points were reported at 3.5% and 3.45% of GDP for total environmental taxes, 2.13% and 2.40% for energy taxes, 0.75% and 0.88% for transport taxes, and 0.1% and 0.02% for pollution taxes in the short run and long run, respectively. Given the estimated thresholds above, policymakers in Kenya, Uganda, and Rwanda should thus focus on each category of environmental taxes rather than treating them as a whole, since their effectiveness in reducing carbon emissions varies by type and may diminish once certain thresholds are reached.

Despite the key findings presented in this study, it is also worth noting potential limitations. First, the study considered a small number of countries due to limited data on environmental taxes and a small sample size of only 22 years. This limited the use of advanced econometric methods, such as dynamic panel-data regression and the Generalised Method of Moments (GMM), to address potential pitfalls in static panel-data models, including endogeneity and reverse causality. Therefore, future studies should consider using larger sample sizes to generalise the empirical findings. Secondly, environmental tax revenues can be influenced by macroeconomic conditions, commodity prices, and policy responses to changing CO2 emissions, so reverse causality and omitted shocks or variables cannot be ruled out.

Funding and Acknowledgements: This study was conducted with support from the International Growth Centre (IGC) Research Fellowship. The author gratefully acknowledges the IGC for research support and for facilitating the development of this work. The author also acknowledges Dr Sseruyange John and Dr Ssajjabi Vincent for their invaluable guidance in conceptualising the research idea. Further appreciation is extended to Professor François Gerard for his guidance and mentorship throughout the research process.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used in this study are publicly available from the OECD and the World Bank World Development Indicators. Replication files are available from the corresponding author upon reasonable request.

Conflicts of Interest: The author declares no conflict of interest.

Clinical Trial Number: Not applicable.

Ethics Approval and Consent to Participate: Not applicable. This study used publicly available secondary data from the OECD and the World Bank's WDI. No human participants or identifiable personal data were involved.

References

- Adeleye, B. N., Akam, D., Inuwa, N., James, H. T., & Basila, D. (2023). Does globalization and energy usage influence carbon emissions in South Asia? An empirical revisit of the debate. *Environmental Science and Pollution Research*, 30(13), 36190-36207.
- Ahmad, M., & Satrovic, E. (2023). Modeling combined role of renewable electricity output, environmental regulations, and coal consumption in ecological sustainability. *Ecological Informatics*, 75, 102121.
- Akkaya, Ş., & Hepsag, A. (2021). Does fuel tax decrease carbon dioxide emissions in Turkey? Evidence from an asymmetric nonlinear cointegration test and error correction model. *Environmental Science and Pollution Research*, 28, 35094-35101.
- Al Shammre, A. S., Benhamed, A., Ben-Salha, O., & Jaidi, Z. (2023). Do environmental taxes affect carbon dioxide emissions in OECD countries? Evidence from the dynamic panel threshold model. *Systems*, 11(6), 307.
- Andersson, J. J. (2019). Carbon taxes and CO2 emissions: Sweden as a case study. *American Economic Journal: Economic Policy*, 11(4), 1-30.
- Aydin, C., & Esen, Ö. (2018). Reducing CO2 emissions in the EU member states: Do environmental taxes work? *Journal of Environmental Planning and Management*, 61(13), 2396-2420.
- Chen, M., Jiandong, W., & Saleem, H. (2022). The role of environmental taxes and stringent environmental policies in attaining the environmental quality: Evidence from OECD and non-OECD countries. *Frontiers in Environmental Science*, 10, 972354.
- Connolly-Boutin, L., & Smit, B. (2016). Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change*, 16(2), 385-399.
- Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the national academy of sciences*, 94(1), 175-179.
- Doğan, B., Chu, L. K., Ghosh, S., Truong, H. H. D., & Balsalobre-Lorente, D. (2022). How environmental taxes and carbon emissions are related in the G7 economies? *Renewable Energy*, 187, 645-656.
- Domguia, E. N., Nkengfack, H., Pondie, T. M., & Ngounou, B. A. (2024). Do environmental taxes encourage the decarbonization of economies? *Environment, Development and Sustainability*, 1-34.
- Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of economics and statistics*, 80(4), 549-560.
- Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth: Complacency concerning this component of man's predicament is unjustified and counterproductive. *Science*, 171(3977), 1212-1217.
- Esen, Ö., Yıldırım, D. Ç., & Yıldırım, S. (2021). Pollute less or tax more? Asymmetries in the EU environmental taxes–Ecological balance nexus. *Environmental Impact Assessment Review*, 91, 106662.
- Ewane, E. B., & Ewane, E. I. (2023). Foreign direct investment, trade openness and environmental degradation in SSA countries. A quadratic modeling and turning point approach. *American Journal of Environmental Economics*, 2(1), 9-18.
- Gujarati, D. N. (2002). Basic Econometrics 4th ed. In.
- Gujarati, D. N. (2009). Basic econometrics. In: McGraw-Hill.
- Guo, L., & Wang, Y. (2018). How does government environmental regulation “unlock” carbon emission effect?—Evidence from China. *Chinese Journal of Population Resources and Environment*, 16(3), 232-241.
- Harris, R. D., & Tzavalis, E. (1999). Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of econometrics*, 91(2), 201-226.

- Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica: journal of the Econometric Society*, 1251-1271.
- Liddle, B. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. *Population and environment*, 35(3), 286-304.
- Mehta, D., & Derbeneva, V. V. (2024). Assessing the Impact of Environment Tax on Carbon Emissions of African Countries. *J. Tax Reform*, 10, 510-523.
- Meireles, M., Robaina, M., & Magueta, D. (2021). The effectiveness of environmental taxes in reducing CO2 emissions in passenger vehicles: the case of Mediterranean countries. *International Journal of Environmental Research and Public Health*, 18(10), 5442.
- Mpofu, F. Y. (2022). Green Taxes in Africa: opportunities and challenges for environmental protection, sustainability, and the attainment of sustainable development goals. *Sustainability*, 14(16), 10239.
- Ocansey, E. O., & Haywood-Dadzie, D. O. (2025). IMPACT OF ENVIRONMENTAL TAXES ON CARBON EMISSIONS: SYSTEMATIC REVIEW. *Development*, 8(5), 18-42.
- Pedroni, P. (2001). Fully modified OLS for heterogeneous cointegrated panels. In *Nonstationary panels, panel cointegration, and dynamic panels* (pp. 93-130). Emerald Group Publishing Limited.
- Pigou, A. (2017). *The economics of welfare*. Routledge.
- Polinsky, A. M., & Shavell, S. (1982). Pigouvian taxation with administrative costs. *Journal of Public Economics*, 19(3), 385-394.
- Poumanyong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. *Ecological economics*, 70(2), 434-444.
- Ramsey, J. B. (1969). Tests for specification errors in classical linear least-squares regression analysis. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 31(2), 350-371.
- Roach, B., Lennox, E., & Codur, A.-M. (2019). Microeconomics and the Environment. *Global Development and Environment Institute, Tufts University: Medford, OR, USA*.
- Sarpong, K. A., Xu, W., Gyamfi, B. A., & Ofori, E. K. (2023). Can environmental taxes and green-energy offer carbon-free E7 economies? An empirical analysis in the framework of COP-26. *Environmental Science and Pollution Research*, 30(18), 51726-51739.
- Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17(6), 1585-1600.
- Sinn, H.-W. (2015). Introductory comment—the green paradox: A supply-side view of the climate problem. *Review of Environmental Economics and Policy*.
- Sohag, K., Bamanga, U., & Alam, M. (2018). Stata command for panel data analysis. *Method, doi*, 10.
- Sterner, T., Dahl, C., & Franzen, M. (1992). Gasoline tax policy, carbon emissions and the global environment. *Journal of transport economics and policy*, 109-119.
- Sun, Y., Hao, Q., Cui, C., Shan, Y., Zhao, W., Wang, D., Zhang, Z., & Guan, D. (2022). Emission accounting and drivers in East African countries. *Applied Energy*, 312, 118805.
- Tao, R., Umar, M., Naseer, A., & Razi, U. (2021). The dynamic effect of eco-innovation and environmental taxes on carbon neutrality target in emerging seven (E7) economies. *Journal of environmental management*, 299, 113525.
- Telatar, O. M., & Birinci, N. (2022). The effects of environmental tax on Ecological Footprint and Carbon dioxide emissions: a nonlinear cointegration analysis on Turkey. *Environmental Science and Pollution Research*, 29(29), 44335-44347.

- Tzavalis, E. (2002). Structural breaks and unit root tests for short panels. *Queen Mary University of London, unpublished*.
- Ulucak, R., Danish, & Kassouri, Y. (2020). An assessment of the environmental sustainability corridor: Investigating the non-linear effects of environmental taxation on CO2 emissions. *Sustainable Development*, 28(4), 1010-1018.
- Wolde-Rufael, Y., & Mulat-Weldemeskel, E. (2021). Do environmental taxes and environmental stringency policies reduce CO2 emissions? Evidence from 7 emerging economies. *Environmental Science and Pollution Research*, 28(18), 22392-22408.
- World Bank. (2022). Environmental Tax. *Global Tax Program*. <https://www.worldbank.org/en/programs/the-global-tax-program/environmental-taxes#1>
- Xie, P., & Jamaani, F. (2022). Does green innovation, energy productivity and environmental taxes limit carbon emissions in developed economies: Implications for sustainable development. *Structural Change and Economic Dynamics*, 63, 66-78.
- York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecological economics*, 46(3), 351-365.
- Zaghdoudi, T., & Maktouf, S. (2017). Threshold effect in the relationship between environmental taxes and CO2 emissions: A PSTR specification. *Economics Bulletin*, 37(3), 2086-2094.

Appendix

Table 3 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) env_tax	1.000						
(2) ener_tax	0.855 (0.000)	1.000					
(3) pol_tax	0.103 (0.409)	0.441 (0.000)	1.000				
(4) tra_tax	0.483 (0.000)	-0.038 (0.760)	-0.597 (0.000)	1.000			
(5) gdp_pc	0.467 (0.000)	0.064 (0.609)	-0.139 (0.267)	0.765 (0.000)	1.000		
(6) energy_int	0.170 (0.176)	0.582 (0.000)	0.610 (0.000)	-0.663 (0.000)	-0.407 (0.001)	1.000	
(7) urb share	0.434 (0.000)	0.630 (0.000)	0.302 (0.014)	-0.218 (0.079)	-0.191 (0.124)	0.301 (0.015)	1.000
Mean VIF	4.32						

Source: Authors' computation based on IMF and OECD data

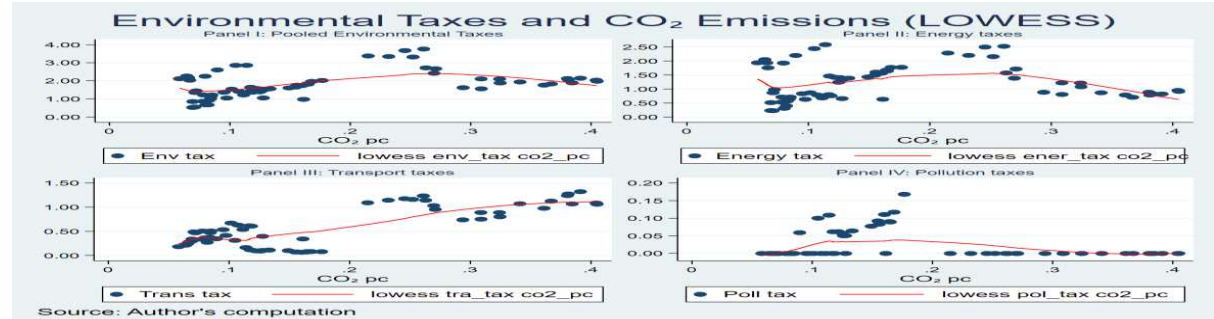


Figure 2 LOWESS Smoothing of Environmental Taxes on CO2 Emissions. Source: Authors' computation based on OECD data

Table 4 Total Environmental Taxes and Carbon Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
env_tax	-0.0599** (0.0274)	-0.0280 (0.0200)	-0.0599** (0.0274)	-0.0280** (0.0127)	-0.0415*** (0.0000)
env_taxsq	0.0117** (0.0058)	0.0035 (0.0044)	0.0117** (0.0058)	0.004 (0.0030)	0.0060*** (0.0000)
gdp_pc	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0003*** (0.0000)
energy_int	0.0024 (0.0017)	0.0178*** (0.0048)	0.0024 (0.0017)	0.0178*** (0.0048)	0.0085*** (0.0000)

urb_share	0.0004 (0.0011)	0.0029*** (0.0010)	0.0004 (0.0011)	0.0029*** (0.0010)	0.0025*** (0.0000)
linear					-0.0016*** (0.0000)
Turning point				3.5	3.45
Constant	-0.0672*** (0.0205)	-0.2035*** (0.0659)	-0.0672*** (0.0205)	-0.2035** (0.0753)	-0.0675*** (0.0000)
Observations	65	65	65	65	64
R-squared	0.9501	0.8399			0.8611
RESET F-statistics	52.30[0.000]				
Number of countries		3	3	3	3
Hausman test		68.96[0.000]			
Heteroskedasticity test		5.980[0.113]			
Serial Correlation test		41.12[0.024]			
CD Test		-1.330[0.184]			
F-stat				100.8[0.000]	
Wald chi2			1123[0.000]		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. Source: Authors' computation

Table 5 Energy Taxes and Carbon Dioxide Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
ener_tax	-0.1021*** (0.0284)	-0.0655*** (0.0232)	-0.1021*** (0.0284)	-0.0655*** (0.0194)	-0.0696*** (0.0000)
ener_tax_sq	0.0291*** (0.0094)	0.0154** (0.0073)	0.0291*** (0.0094)	0.0154*** (0.0047)	0.0145*** (0.0000)
gdp_pc	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)
energy_int	0.0045*** (0.0017)	0.0137*** (0.0046)	0.0045*** (0.0017)	0.0137*** (0.0042)	0.0108*** (0.0000)
urb_share	0.0013 (0.0011)	0.0032*** (0.0009)	0.0013 (0.0011)	0.0032*** (0.0008)	0.0035*** (0.0000)
linear					-0.0014*** (0.0000)
Turning point				2.13	2.40
Constant	-0.0829*** (0.0167)	-0.1365** (0.0670)	-0.0829*** (0.0167)	-0.1365* (0.0734)	-0.0942*** (0.0000)
Observations	65	65	65	65	64
R-squared	0.9573	0.8553			0.8036
RESET F	39.64[0.000]				
Number of countries		3	3	3	3
Hausman test		62.74[0.000]			

Heteroskedasticity test	37.59[0.000]	
Serial Correlation test	42.07[0.023]	
CD test	-0.480[0.629]	
F-stat		67.39[0.000]
Wald chi2		1323

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. CD refers to cross-sectional dependence. Source: Authors' computation

Table 6 Pollution Taxes and Carbon Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
pol_tax	-0.6121** (0.2594)	0.9187*** (0.2631)	-0.6121** (0.2594)	0.9187*** (0.2821)	0.0472*** (0.0127)
pol_tax_sq	2.6950 (1.9198)	-4.7263*** (1.6401)	2.6950 (1.9198)	-4.7263** (1.7203)	-1.0053*** (0.0852)
gdp_pc	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)
energy_int	0.0033* (0.0018)	0.0299*** (0.0046)	0.0033* (0.0018)	0.0299*** (0.0048)	0.0050*** (0.0001)
urb_share	0.0027** (0.0013)	0.0033*** (0.0009)	0.0027** (0.0013)	0.0033*** (0.0009)	0.0023*** (0.0001)
linear					-0.0017*** (0.0000)
Turning point				0.097	0.024
Constant	-0.1293*** (0.0236)	-0.3779*** (0.0553)	-0.1293*** (0.0236)	-0.3779*** (0.0595)	-0.0636*** (0.0011)
Observations	65	65	65	65	64
R-squared	0.9520	0.8561			0.7019
RESET F	63.03[0.000]				
Number of countries		3	3	3	3
Hausman test		25.48[0.000]			
Heteroskedasticity test		1.980[0.576]			
Serial Correlation test		390.7[0.003]			
CD test		-0.610[0.540]			
F-stat				189.5[0.000]	
Wald chi2			1170		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. Source: Authors' computation

Table 7 Transport Taxes and Carbon Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
tra_tax	0.0685 (0.0474)	-0.1173** (0.0473)	0.0685 (0.0474)	-0.1173*** (0.0275)	-0.0751*** (0.0015)
tra_tax_sq	0.0069 (0.0320)	0.0665** (0.0261)	0.0069 (0.0320)	0.0665** (0.0239)	0.0504*** (0.0009)
gdp_pc	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)	0.0003*** (0.0000)	0.0002*** (0.0000)
energy_int	0.0046** (0.0020)	0.0212*** (0.0041)	0.0046** (0.0020)	0.0212*** (0.0036)	0.0035*** (0.0001)
urb_share	0.0045*** (0.0013)	0.0029** (0.0011)	0.0045*** (0.0013)	0.0029* (0.0016)	0.0027*** (0.0000)
linear					-0.0015*** (0.0000)
Turning point				0.88	0.75
Constant	-0.1520*** (0.0334)	-0.2480*** (0.0550)	-0.1520*** (0.0334)	-0.2480*** (0.0526)	-0.0428*** (0.0011)
Observations	65	65	65	65	64
R-squared	0.9575	0.8425			0.8291
RESET F	34.48[0.000]				
Number of countries	3	3	3	3	3
Hausman test		45.09[0.000]			
Heteroskedasticity test		3.790[0.285]			
Serial Correlation test		61.01[0.016]			
CD test		-1.810[0.071]			
F-stat				143.5[0.000]	
Wald chi2			1328		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. Source: Authors' computation