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TÁC ĐỘNG CỦA THUẾ MÔI TRƯỜNG ĐẾN ĐỔI MỚI CÔNG NGHỆ XANH: BẰNG CHỨNG THỰC NGHIỆM TỪ CÁC QUỐC GIA CÓ THU NHẬP TRUNG BÌNH

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Tóm tắt

Nhiều nghiên cứu đã tìm hiểu tác động của thuế môi trường đối với việc đạt được các mục tiêu phát triển kinh tế và giảm thiểu suy thoái môi trường ở các quốc gia. Tuy nhiên, số lượng các nghiên cứu điều tra vai trò của thuế môi trường trong việc thúc đẩy đổi mới công nghệ xanh còn hạn chế. Bài báo này được đề xuất với mục tiêu giải quyết khoảng trống này, thông qua việc xác định tác động của thuế môi trường đối với đổi mới công nghệ xanh ở 13 quốc gia có thu nhập trung bình trong khoảng thời gian từ 2000 đến 2020, sử dụng mô hình Độ trễ Phân phối Tự động theo Nhóm Trung bình Gộp (PMG-ARDL). Để kiểm tra độ tin cậy của mô hình PMG-ARDL, hai phương pháp thay thế là FMOLS và DOLS cũng được sử dụng. Kết quả cho thấy thuế môi trường có tác động tích cực đến đổi mới công nghệ về môi trường trong dài hạn; ví dụ, mức thuế tăng 1% có thể thúc đẩy 0,621% tăng trưởng trong đổi mới công nghệ xanh ở các nước thu nhập trung bình. Tuy nhiên, kết quả trong ngắn hạn cho thấy tác động tiêu cực giống với nhận định của giả thuyết Porter. Cuối cùng, nghiên cứu cũng đưa ra một số kiến nghị cho việc xây dựng và thực hiện các chính sách thuế môi trường sao cho phù hợp để thúc đẩy quá trình chuyển đổi công nghệ xanh và hướng tới đạt được sự phát triển bền vững ở các nước thu nhập trung bình.

Từ khóa: Tác động của thuế, Phát triển kinh tế, Thuế môi trường, Đổi mới công nghệ môi trường.

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IMPACTS OF ENVIRONMENTAL TAXES ON ENVIRONMENTAL TECHNOLOGICAL INNOVATION: EMPIRICAL EVIDENCE OF MIDDLE-INCOME COUNTRIES

Abstract

Several studies have delved into the efficacy of environmental taxes in achieving economic development goals and reducing environmental degradation in countries. However, scant attention has been directed towards investigating the role of environmental taxes on fostering environmental technological innovation. This study aims to address this gap by meticulously examining the impacts of environmental taxation on environmental-related technological innovation across a selection of 13 middle-income countries spanning the years 2000 to 2020, employing the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) approach. For robustness check of the PMG-ARDL model, two alternative approaches, namely FMOLS and DOLS are also employed. The results reveal that environmental taxation has a significant positive long run impact on the technological innovation in the field of environment; for example, a 1% increase in the level of taxation could stimulate 0.621% growth in the green technological innovation of middle-income countries, implementing the PMG. However, the short-run results indicate an adverse impact, supporting the Porter hypothesis. The study offers some important recommendations for designing and implementing appropriate environmental tax policies to promote the transition to green technology and to achieve sustainable development in middle-income countries.

Keywords: Tax impact, Environmental taxes, Environmental-related technological innovation, middle-income countries.

1. Introduction

The imperative of maintaining sustainable environmental quality is underscored as an essential component of achieving sustainable economic progress. However, the economic expansion activities have shown detrimental impacts on the environment since the mid-20th century, exemplified by a significant increase in greenhouse gas emissions, notably carbon dioxide emissions. In 2017, global energy consumption surged by 1.9% (IEA, 2018), primarily led by developing economies, with an anticipated 90% increase expected by 2035 (OECD, 2011). This increase in emissions is largely attributed to developing nations, primarily because they heavily depend on fossil fuels to fuel their rapid economic expansion, leading to a host of environmental issues, particularly related to emissions. According to the United Nations, around 50% of global emissions originate from low- and middle-income countries, a proportion expected to rise as these nations progress further. Therefore, the implementation of effective environmental policies in these developing countries are imperative to mitigate global warming and curb emissions (United Nations, 2017).

Such profound environmental deterioration resulting from human socio-economic endeavors has called for urgent and substantial actions, prompting governments to consider implementing environmental taxes as a means of alleviating these issues. Environmental taxes serve as a potent mechanism for addressing externalities by internalizing the societal expenses associated with environmental degradation and ecological destruction. Through the implementation of judicious environmental taxation, it becomes possible to mitigate the costs of environmental damage, effectively diminish pollution, and enhance ecological conditions. In the same way, there was a notable consensus among experts and economists regarding the significance of eco-innovations or green technologies as potent instruments for attaining environmental sustainability since their integration into production processes facilitates enhancements in efficiency, reduces energy consumption, and enables the adoption of clean energy sources (Huang et al., 2020). In alignment with the well-known Porter hypothesis (Porter and Van der Linde, 1995), it stands to reason that efficient environmental policies should incentivize the development of green innovations.

There has been a global trend for the adoption of environmental taxation and environment-focused technological innovations driven by social and economic development imperatives. However, the integration of these practices in developing nations is a relatively recent phenomenon, giving a necessity to clarify the interplay and correlation between environmental taxes and green technological innovation along with the understanding the direction and magnitude of these relationships, constituting the primary objective of the current study. Thus, the aim of this paper is to investigate the short-run and long-run impacts of environmental taxes on green technological innovation of 13 middle income countries from 2000 to 2020 by applying the PMG-ARDL approach, then propose tax policy designs for green technology innovation development. The subsequent sections of this paper are structured as follows: Section 2 offers an overview of empirical literature. Section 3 outlines our empirical methodology. Section 4 delves into the empirical findings and results. Following that, Section 5 presents the policy implications, and Section 6 concludes.

2. Literature Review

2.1. Environmental Tax

Governments implement various regulatory measures, such as environmental taxes, aiming to mitigate carbon emissions and address other environmental problems (Halkos, G.E., 2018). Environmental taxes are primarily imposed to tackle issues of free-riding and externalities, incentivizing consumers to adjust their consumption patterns towards sustainability by raising the prices of environmentally harmful goods compared to those with lower environmental impacts (Williams RC., 2017). These taxes encompass a range of levies including those on transportation, carbon emissions, energy usage, pollution discharges, and CFCs. However, the collection, enforcement, and impact of these taxes vary among countries. Additionally, environmental taxes elevate the costs of production inputs, prompting producers to embrace more eco-friendly technologies and processes (Kosonen K., 2012). The primary objective of environmental taxes is not revenue generation or profit enhancement but rather behavioral change by holding individuals and businesses accountable for environmental externalities (ICC, 2013). Furthermore, environmental taxes furnish financial resources to local authorities and governments, which can be allocated towards initiatives promoting ecological practices aimed at reducing CO_2 emissions (Aydin C., 2018).

Since its proposal in the 1990s by the OECD, the concept of environmental taxation has gained gradual acceptance, prompting many developed nations to establish their own systems while developing countries have begun their forays into its implementation. Many developing countries have already introduced carbon taxes at a domestic level, among which are middle-income countries (UN, 2021). However, the comprehensive evaluation of the impact of such taxes, considering socioeconomic and environmental factors, reveals potential challenges to these economies, including adverse effects on economic growth (Li G., Masui T., 2019). Those challenges could be solved by eco-innovation and renewable energy technologies without compromising environmental integrity. Depending on their level of development and reform depth, the tax components integrated into environmental taxation schemes may vary. For instance, developed countries have commonly implemented carbon taxes based on the carbon content or CO_2 emissions from fossil fuels, while many developing nations have adopted energy taxes based on energy prices.

2.2. Environment-related Technological Innovation

In addition to strict environmental regulations, green technology innovation is a critical element in effectively minimizing the ecological footprint of human activities. Green technology innovation refers to the act of developing environmentally friendly new technologies for products and processes. It aims to harness the economic advantages brought by technological advancements while simultaneously striving for the ecological benefits of cleaner energy and reduced emissions (Guo Y., Xia X., Zhang S., Zhang D., 2018).

Environment-related technological innovation fosters the development and adoption of environmentally friendly technologies, which play a crucial role in monitoring, controlling, and mitigating pollution throughout the entire production process and product lifecycle. Essentially, these technologies aim to minimize or eliminate pollution and environmental degradation stemming from both manufacturing processes and the use of final products. Through innovation in green technology, objectives such as pollution reduction, enhanced efficiency, effective management of negative environmental impacts, and overall improvement in environmental quality can be achieved. Furthermore, research and development endeavors demonstrate that advancements in green technology yield cutting-edge systems that are less polluting and facilitate the conservation of resources such as raw materials, water, and gases. These innovations not only bolster the efficiency and productivity of businesses but also contribute to a more sustainable and environmentally conscious approach to production and consumption. (Wang and Liu, 2021).

As environment-related technological innovation contributes to reconciling environmental preservation with economic progress, which is a fundamental dynamic for fostering a sustainable society (Sun et al., 2008), the global significance of green technology has surged, particularly in middle-income countries. For instance, the Chinese government has been actively promoting industrial capacity building through innovation-led manufacturing, industrial optimization, quality enhancements, and green development initiatives (Li, 2018). Similarly, other middle-income economies are getting ready to take advantage of frontier technologies, including blockchain, drones, gene editing, nanotechnology, and solar power, by preparing capacities needed which rely on digitalization and connectivity (UNCTAD, 2023). Asian economies have implemented significant policy reforms, allowing them to outperform expectations relative to their GDP per capita.

2.3. Overview of prior empirical studies

Current research advocate mixed viewpoints regarding impacts running from environmental tax towards green technological innovation including positive and negative associations while others indicate the relationship is U-shaped with dependence on pollution severity and other factors for inverted U-shape. Using cross-country panel data analysis, Karmaker et al. (2021) evidenced environmental taxes have a long-run causal relationship with the goal of green technological innovation. Levels of environmental tax have a statistically positive impact on green innovation, specifically 1% increase in environmental taxes stimulates 0.57% and 0.78% on average growth in tech innovation (i.e., green patents) for high and middle-income countries using the CCMG and AMG models, respectively. There are various opinions regarding the U-shaped relationship between environment tax and green innovation in eastern and middle areas China while the same result is not clear in the west, indicating different effects in different regions (Wenyuan and Yirui, 2017; Liu et al., 2022). These taxes may initially suppress innovation in the short run but could raise it in the long run due to lagging tax effects (Jiang, Xu and Zhou, 2022). Another explanation is the threshold effect of environmental regulation including taxes and R&D investment, only when the thresholds are crossed, the influence on ecological innovation can be established (Zhou et al., 2020). The relationship is found varied across manufacturing firms within different pollution severity from serious to light pollution (Ling and Feng, 2012; Zhou et al., 2020).

How environmental taxes channel its effect on technological innovation is a debating issue within the environment, development and the design of environmental tax (Itaya, 2008). Several studies indicate tax pressure on production cost and customer consumption concept as an incentive for firms' green innovation, with the innovation merits partially offsetting the cost effect injected by environmental regulations (Porter and Linde, 1995). Prices increased in production inputs resulting from environmental taxes induce the producers to adopt more environmentally friendly technologies (Kosonen, 2012; Lei, Huang and Cai, 2022). As firms and consumers respond to tax put on pollution, investing in R&D activities to generate consumer products with lighter environmental footprint is economically attractive (Fan, Li and Yin, 2019). Porter's hypothesis reveals that these taxes catalyze firm investment in R&D and further support green innovation (Huang et al., 2022). Environmental tax can firstly force firms to carry out green innovation, then guide them to stimulate enthusiasm to reduce risk and increase market share by taking the lead in green innovation (Ni and Ma, 2023). On the other hand, scholars propose opposite views that imposing environmental tax will inevitably result in a crowding out effect with reduced investment in technological advancement as enterprises' regulatory and financial costs rise (Zhou et al., 2020), business risk increases and rising operating cost reduces expenses on R&D. Also, risk of improvement failure, external changes and inertial obstacles hinder firms' implementation of green innovation (Ni and Ma, 2023).

Green technological innovation takes different forms, including new tech developed, existing tech optimized and a hybrid approach (Karmaker et al., 2021). According to OECD (2010), imposing price on pollution creates incentives for various forms of innovation, which account for taxation's advantages over other prescriptive environmental policies in its dual target of cleaner production process innovation and end-of-pipe pollution control innovation. Höglund-Isaksson study on Sweden NOx tax suggests that taxation provides growing incentives for firms lacking resources to formalize R&D practices to increasingly adopt existing abatement technology developed elsewhere. However, case studies do not evidence that environment-related taxation always undeniably result in new technologies and innovation. Climate change tax in the UK drives general innovation, not specifically climate change-related innovation (OECD, 2010).

The studies of environmental tax's impact on green technological innovation both at micro and macro level present mediating factors affecting the relationship. Financing constraints inversely moderate the association between environmental taxes and technological advancement, steady government financial support allows firms to develop green technologies and enhance production processes (Ding and Petrovskaya, 2022). Further analysis shows that pollution level, market competition, economic growth pressure and degree of economic development are factors mediating the relationship between environmental protection tax and green innovation (Jiang, Xu, and Zhou, 2022; Wang, Li and Wang, 2023). Other constraints include factors at country-level and firm level, such as resources constraints, crowding-out, crowding-in and optimal R&D allocation (OECD, 2010).

The possible contributions of this paper resolve the following research gaps. First, existing studies have focused on firm-based data with small sample sizes from a micro perspective to extract environmental protection tax influence on environmental and economic performance while its role in promoting green innovation using country-level data remains less considered. Second, there remains a need to quantify the effect of environmental taxes on technological innovation in middle income countries. Karmaker et al. (2021) successfully studied the role of environmental taxes on technological advancement using panel data from high and upper-middle income 42 countries. However, previous research show that the impacts on green technological innovation vary according to region, economic development, and other pollution-related factors (Wenyuan and Yirui, 2017; Liu et al., 2022; Zhao et al., 2022). Hence, focused examination should be taken specifically on middle-income nations. Third, among previous quantitative research, there is no consensus on the conclusions regarding the impact of environmental tax on green technological innovation as the association may vary between nations, regions, and pollution severity. Particularly, the variation in the short-run and long-run association between tax on environmental-related criteria and green innovation in technology in growing economies has not yet been clarified by earlier researchers. In this study, the authors conduct the panel autoregressive distributed lags considering cross-sectional dependence to measure the impact of environmental taxes on green technological innovation. Quantitative research based on data from middle income countries explores the evidence and quantifies the interplay between technological innovation and environmental taxes from 2000 to 2020. Using the PMG-ADRL model to assess the impact in both short run and long run, this research aims to add to the previous studies, simultaneously providing new insights on a macro perspective.

3. Methodologies

3.1. Econometric model

Karmaker et al. (2021) has fully explored the role of environmental tax on technological innovation. Following the model in Karmaker et al. (2021), the general functional form of the econometric model for studying the effect of environmental taxation on environment-related technological innovation in 13 middle income countries is suggested as followed:

$$ETI_{it} = f(\, ET_{it}, GDP_{it}, RD_{it})$$

In order to reduce the problems of autocorrelation and heteroscedasticity, the authors consider the natural logarithms of variables, and the log-linear form of the model will be suggested as follow:

$$ln(ETI)_{it} = \tau_0 + \beta\ ln(ET)_{it} + \tau_1 ln(GDP)_{it} + \tau_2 ln(RD)_{it} + \varepsilon_{it}$$

In which:

i (=1 … …, N) represents the studied countries (13 middle income countries)

t (=1 … …, T) represents the year from 2000 to 2020

β is the coefficient of technological innovation

τ_1, τ_2 is respectively the coefficient of economic growth and research and development expenditure.

ε_{it} indicate the random error term in the model.

$ln(ETI)_{it}$ is the dependent variable in this research, corresponding to the natural logarithm of the number of patents in environmental-related technologies in the country i at time t. It serves as the proxy for the level of green technological innovation in the studied countries.

$ln(ET)_{it}$ is the most important independent variable in the model. It is the natural logarithm of the amount of environmental-related tax revenue in million of USD in the country i at time t. Environmental taxes are predicted to have either a negative or positive impact on green innovation. This is explained primarily by the U-shape relationship between environmental taxation and green innovation, or in other words the Porter's hypothesis validated by Zhang et al. (2019) and Du et al. (2019). In the short-term implementation, under weak regulation, increasing tax intensity prompts enterprises to focus on addressing environmental pollution issues rather than investing in R&D activities. This was believed to reduce the green innovation capacity of the enterprises. On the other hand, in the long run, with proper controllation, environmental taxation prompts companies to conduct innovation investment to minimize its business impact on the environment while optimizing the input–output efficiency.

$ln(GDP)_{it}$ and $ln(RD)_{it}$ are considered as the controlled variables in the model. Specifically, $ln(GDP)_{it}$ is the natural logarithm of GDP per capita in the country i at time t, while $ln(RD)_{it}$ represent the natural logarithm of expenditure of country i on research and development activities at time t, measured by the ratio to GDP. In the case of the GDP indicator, a large amount of past research has shown that the higher the country's economic level is, the more resources are provided to support technological innovation, especially those that aim at environmental issues. However, the Environmental Kuznets Curves hypothesis suggested there will always be a trade-off between the increase in per capita income and environment in the early stage of economic growth, particularly in the situation of middle-income countries. The middle-income nations decide to prioritize fostering economic growth rather than paying close attention to environmental issues and environmental protection; thus, discouraging green technological innovation as the economy grows further. The expenditure on research and development is also expected to generate positive effects on the number of patents of environment-related technological innovation as gross domestic expenditure on research and development plays a crucial role in driving innovation in environment-related technologies by providing funding, incentives, collaboration opportunities, and policy support.

3.2. Data sources

The data for the research was extracted from the annual data of 21 years from 2000 to 2020 of 13 middle-income nations. The data collected include environmental taxes in millions of USD, environment-related technological innovation in terms of the number of patents in environment-related technologies, the level of economic growth through GDP per capita, and the gross domestic expenditure on research and development as percent of GDP. We chose the 13 middle-income countries due to the availability of data for all proposed series in this study. The study was conducted on the basis of country-level panel data with N = 13 and T = 21, which equals to N*T = 273 observations.

Table 1: Description of variables

Variable	Description	Symbol	Measure	Data source
Environment-related technological innovation	The number of patents in environmental-related technologies	ETI	patents	OECD database
Environmental Tax	Total tax revenue in relation to environment	ET	million USD	OECD database
Economic Growth	The gross domestic product divided by midyear population.	GDP	USD per capita	World Bank
Research & development	The ratio of gross domestic expenditure on R&D activities to GDP	RD	% (of GDP)	World Bank

Source: Summarized by authors, 2024

3.3. Methods of Estimation

In this study, we employ the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model proposed by Pesaran et al. (1999) to explore the role of environmental taxes on environmental-related technological innovation of 13 middle-income countries from 2000 to 2020.

3.3.1. Cross-sectional Dependence tests

Firstly, we perform the cross-sectional dependence tests, using the Breusch and Pagan's LM test and the Pesaran's CD test to identify the cross-sectional dependency problems in the panel data. The scenario of globalization and economic collaboration has been accelerating the interference of one nation's variables with that of other nations, which necessitates the cross-sectional dependency testing to avoid bias results. The null hypothesis assumes that the cross-sectional units are independent, while the alternative hypothesis is dependency between cross-sectional units.

3.3.2. Panel unit root tests

The panel root test is applied to find the order of integration of the panel data. This test typically involves estimating a regression model that incorporates both cross-sectional and time dimensions, and then examining whether the residuals from this model exhibit characteristics of stationary process (non-stationary or stationary). In the presence of cross-sectional dependence, we conduct the second-generation panel unit root test - Pesaran's CIPS to ensure the stability of the panel data. These tests indicate the null hypothesis as every variable is non-stationary (or I(0)), whereas the alternative implies that there is at least one variable that has a unit root in the panel.

3.3.3. Panel cointegration test

Once the null hypothesis of non-stationary is rejected, panel cointegration tests (Kao, 1999; Pedroni, 1999; Westerlund, 2005) could be conducted to identify the long-run relationship among variables. The null hypothesis is determined as there is no cointegration, while the alternative hypothesis indicates that all panels are cointegrated.

3.3.4. Short-run and long-run effects

The evaluation of short-run and long-run cointegration correlation are conducted using the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL), proposed by Pesaran et al. (1999). PMG-ARDL allows for the estimation in the restricted sample data and handles the problems of heterogeneity bias. In the PMG model, no variation restriction is required on all the dynamics and ECM terms, and the parameters for stationary and non-stationary regressors are asymptotically normal and consistent thanks to the regularity assumptions embedded within the model. We also perform the Hausman test to validate the suitability of employing the PMG-ARDL approach for qualifying the short-term and long-term relationships among variables. Statistically insignificant p-value of the Hausman test proves the appropriateness of PMG estimates for the research rather than the MG estimates.

Additionally, since the optimal lag length is required, the sequential modified LR test statistic (LR), final prediction error (FPE), Akaike information criterion (AIC) and Hannan-Quinn information criterion are applied for the optimal lag selection. The results are shown in Table 2

Table 2: Optimal lag order selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1115.481*	NA	0.323	10.223	10.285	10.248
1	168.608	2509.544	3.02e-06	-1.357	-1.047*	-1.232
2	206.060	71.826*	2.5e-06*	-1.553*	-0.995	-1.328*
3	211.246	9.756	2.75e-06	-1.454	-0.649	-1.129

Source: Summarized by authors, 2024

4. Results

4.1. Descriptive Statistics

Table 3 shows the descriptive statistics.

Table 3: Descriptive statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
ETI	273	46.373	143.250	0.161	855.469
ET	273	8885.553	18586.98	-17165.34	119197.1
GDP capita	273	10668.72	6703.686	959.36	27595.6
RD	273	0.870	0.573	0.116	2.564

Source: Summarized by authors, 2024

4.2. Cross-sectional Dependence test

The results of cross-sectional dependence tests are indicated in the table 4 Based on the estimated p-value of the LM and CD test, we have enough statistical evidence to reject the null hypothesis of cross-sectional independence for all the variables in this study. Correspondly, that indicates if any individual country experiences a sudden change, it may also impact the other countries under investigation.

Table 4: Cross-sectional dependence test

Variables	LM test		CD test	
	Test Statistic	p-value	Test Statistic	p-value
lnET	921.163	0.0000	26.858	0.0000
lnETI	365.919	0.0000	16.150	0.0000
lnGDP	1232.602	0.0000	34.885	0.0000
lnRD	819.528	0.0000	18.307	0.0000

Source: Summarized by authors, 2024

4.3. Panel unit root tests

Conducting the Pesaran's CIPS test for cross-sectional dependent panel unit root test, the study came to the conclusion that in case of at level, lnRD are non-stationary at either 1%, 5% or 10% significance level. However, in the case of first difference form, all involved variables were proved to be stationary, making them satisfactory for the PMG-ARDL's requirement. The specific results of CIPS for panel unit root test are shown in Table 5

Table 5: Panel unit root tests

Variable	**CIPS test**	
	Level	**1st difference**
lnET	-2.084***	-2.416***
lnETI	-2.782***	-5.133***
lnGDP	-2.779*	-3.090***
lnRD	-0.338	-3.494***

Source: Summarized by authors, 2024

4.4. Panel cointegration tests

Once the non-stationary panel series in the research has been confirmed, panel cointegration tests including Pedroni (1999,2004), Kao (1999) and Westerlund (2005) would be conducted to test for the long-run relationship within variables. The test results are presented in Table 6, which all reject the null hypothesis of non-cointegration at either 1% or 5% level of significance. In short, the results support a cointegration relationship between dependent variable LnETI and independent variables LnET, LnGDP and LnRD.

Table 6: Panel Cointegration tests

Methods	**t-statistic**
Pedroni (1999, 2004)	
Modified Phillips-Perron t	-2.021**
Phillips-Perron t	-8.086***

Methods	t-statistic
Augmented Dickey-Fuller t	-7.251***
Kao (1999)	
Modified Dickey-Fuller t	-5.557***
Dickey-Fuller t	-7.842***
Augmented Dickey-Fuller t	-3.609***
Unadjusted modified Dickey-Fuller t	-14.178***
Unadjusted Dickey-Fuller t	-10.451***
Westerlund (2005)	
Variance ratio	-1.642**

Source: Summarized by authors, 2024

4.5. Short-run and long-run estimation

Identifying the long-run association within the variables, PMG-ARDL techniques are applied for the short-run and long-run estimation of the impacts of environmental taxation on environmental-related technological innovation. Estimated coefficients and corresponding p-value according to the panel-ARDL model are presented in Table 7

Table 7: PMG estimation results

Variable	Panel - ARDL Analysis Results	
	Coefficient	Probability
PMG estimator (long-run equation)		
LnET	0.621	0.000
LnGDP	-0.296	0.000

Variable	Panel - ARDL Analysis Results	
	Coefficient	Probability
LnRD	0.393	0.000
PMG estimator (short-run equation)		
△lnET	-0.868	0.046
△lnGDP	0.427	0.24
△lnRD	-0.119	0.82
COINTEQ01	-0.571	0.000
Root MSE = 0.568		

Source: Summarized by authors, 2024

The results supported that environmental tax has a significant effect on the green technological innovation at 1% and 5% significant level in the long-run and short-run respectively. However, the impact has been proved to be uncertain, or that is, the relationship is non-linear. To be more specific, a 1% increase in the environmental tax would prompt growth in environmental-related technological innovation (i.e. patents on environmental technologies) by 0.621% in the long-run. However, in the short-run, a 1% increase in the environmental tax leads to a decrease of 0.868% in environmental-related technological innovation. This finding confirms the nonlinear nature in the impacts of environmental tax on green innovation.

Discrepancies in short-term and long-term results are also observable in the control variables (lnGDP and lnRD). In the short run, both the level of economic growth and expenditure on research and development of middle-income countries are found to have no significant impact on the level of green technological innovation. Meanwhile, the evaluation of long-run effects indicated the coefficient between lnETI and control variables is -0.296 for lnGDP, and is 0.393 for lnRD, all significant at the 1% level. That means a 1% increase in the environmental-related technology innovation is accompanied by a 0.296% decrease in the economic level, and by 0.393% increase in the R&D expenditures, indicating high economic growth levels hinder the progress of green technological innovation, while high expenditure on R&D facilitates them.

4.6. Robustness check

Additionally, two substitute single estimators for long-run relationships, namely FMOLS and DOLS, are conducted to evaluate the ARDL estimators. Their results are indicated in Table 8

Table 8: Robustness Check - Long run estimates using FMOLS, DOLS

Variables	FMOLS	DOLS
LnET	0.748***	0.503***
LnGDP	-0.399***	-0.181**
LnRD	0.5504***	0.464***
Adjusted R-squared	0.636	0.7602

Source: Summarized by authors, 2024

The DOLS framework is effective in evaluating the efficiency of variables with mixed order of integration in a cointegration relationship. Theoretically, the DOLS model regresses the variable that is stationary at first difference, or in short I(1), against the variables of I(0) using constant term and I(1) with p-leads and - p lags of the first difference. According to Rafique et al. (2022), the DOLS framework is also appropriate to handle the small sample bias and endogeneity. In line with PMG-ARDL, the results of DOLS indicated that environmental taxation has a significant positive long run impact on the technological innovation in the field of environment; for example, a 1% increase in the level of taxation could stimulate 0.503% growth in the green innovation of middle-income countries, significant at 1% level. Impacts of national economic growth level in terms of GDP per capita and research and development expenditure on environmental - related technological innovation are also supported and consistent with the findings in the PMG estimators. Additionally, the outcome for the FMOLS model is also consistent with PMG and DOLS yet resulting in higher impact.

5. Discussion and Policy Implication

5.1. Discussion

The result proves that an increase in environmental tax results in decrease in green technological innovation in the short run, which is consistent with the inverse section of the U-shaped relationship indicated in previous research. Researchers labeled the pollution level and concluded that the medium and light pollution severity regions record a U-shaped relationship between environmental regulation and green technological progress. The middle-income countries included in this paper mostly belong to the medium polluted group, with regard to air pollution.

Therefore, the relationship between imposing environmental tax and green technological development of those studied cases is U-shaped as expected. Another possible reason for the negative impact is that environmental tax is only a type in the tax system, and it is not enough to extract the green technology effect, which has been proven by previous research on other OECD countries. Wang, Li and Wang (2023) has also pointed out that in the short term, as R&D activities incur high risk, large investment, long cycle and low investment returns, firms incline to pursue "short and quick" projects to achieve higher returns on investment. It results in crowding-out of R&D investment in environmental technology innovation, eventually having a disincentive impact on green technology advancement. On the other hand, this paper's result diverges from other studies supporting a positive relationship between environmental taxes and advancement of green technology. Karmaker et al. (2021) states that environmentally related taxes prompt innovation in green technology as firms respond positively to market signals of market-based tax regulations by creating patents to curb environmental degradation. The differences are explained by the focus on country groups with dissimilar income levels, economic growth and other macro factors mediating the impacts running from the environmental tax to green technological innovation. Furthermore, the positive impact of environmental tax on green technological development might be seen when the government coordinates different kinds of taxes in the tax system. It is because different kinds of tax simultaneously affect R&D investment and firms' adoption of technological advancement; or in other word, increased green innovation can stem from impacts of other taxes rather than environmental tax. In this case, only studying the environmental tax cannot radically explain its impact on green technology innovation (Wang and Yu, 2021).

The test result of long run impacts evidence that environmental tax pushes the advance of environmental-related technology. Several studies based on the Porter effect points out that environmental protection tax provides the compensation effect of firm green management technology innovation, incentivizing firms to increase competitive advantage and enlarge market share. Through studies in the US and EU, similar conclusions were extracted in studies of Chintrakarn (2008) and Calel and Dechezleprêtre (2016). Environmental tax is an externally imposed mandatory constraint which increases the manufacturer's private cost to the threshold that the manufacturer can bear, and from that point, it stimulates manufacturer's active engagement in environmental technology advancement to drive down the compliance cost and utilize clean energy (Tu et al., 2022). Research by Lei, Huang and Cai (2022), Manderson and Kneller (2012), Nesta, Vona and Nicolli (2014), Song, Yang and Zhang (2019) and Shang et al. (2021) all support that the influence of environmental tax on innovation compensation and first-mover advantage remains in the long term, confirming the two core paths of Porter hypothesis. Besides, control variables were ultilized in prior research of environmental taxes impacts on green technology innovation, and came to a consistent result with this paper. Wang, Li and Wang (2023) specified that economic growth pressure with investment in R&D and per-capita real GDP as control variables has an inhibitory impact on green-technology progress and efficiency. Meanwhile, environment-induced R&D effectively facilitates green technology innovation (Zhao et al., 2022).

In conclusion, the results strongly indicate that environmental tax could stimulate the growth of green technological innovation in the long run, yet several obstacles require coordination of other policy instruments. Since no country imposes one single type of environmental tax, but most likely incorporated with excise duty, resource tax and vehicle purchase tax, the interaction of different taxes on green technology innovation may result in different outcomes. Moreover, only environmental tax without other regulations and innovation policies cannot fully realize the dual targets of innovation incentives and environmental effects (Wang and Yu, 2021). Differing levels of socio-environmental factors including individual and firms' behaviors and awareness need to be considered to achieve new clean technology (Karmaker et al., 2021).

5.2. Policy Implications

According to the result of our study, we conclude that environmental taxes can contribute significantly to the drive of developing environment-related technological innovation within middle-income nations. Therefore, the implementation of such measures should be taken seriously and carefully in order to generate positive outcomes on green innovation and national growth. In this sense, based on the findings, the following policy implications are suggested:

First, in middle-income countries, where numerous industries are still in their infancy and undergoing rapid development, namely renewable energy industry, new energy vehicles, etc., the implementation of environmental taxes should be approached gradually. By introducing taxes in stages, governments can allow industries time to adapt while fostering a culture of sustainability. Continuous evaluation and monitoring mechanisms are essential to assess the impact of these taxes on economic growth, innovation, and environmental conservation, while determining the suitable tax amount to achieve the optimal rate of taxation. Through this iterative process, policymakers can refine their strategies, ensuring that environmental taxation effectively incentivizes green innovation without hindering the development of emerging industries.

Second, the absence of fixed or common environmental tax rates among nations has created the challenge of pollution-intensive businesses shifting operations to countries with lower environmental taxation rates. This risk underscores the need for robust regulatory frameworks and international cooperation. Governments must collaborate to establish consistent environmental tax policies while offering tax incentives to promote the transition to green technologies. By fostering a conducive regulatory environment and promoting international coordination, countries can mitigate tax avoidance practices and encourage the adoption of sustainable business practices, driving the shift towards green innovation on a global scale.

Third, middle-income countries have the tendency to prioritize immediate infrastructure investments over long-term green technology development. Moreover, the green technology and infrastructures are not always affordable right away, for instance, 25 to 50% of the average long-term cost of producing clean energy in developing markets like China is attributed to financing or expenses due to borrowing, as mentioned by the Finance for Development Lab. These have been highlighting the importance of increasing awareness and proactive government measures. In the meantime, the governments should allocate dedicated funds for environment-related research and development (R&D), which then fosters green innovation. Moreover, educational campaigns are crucial for enlightening both the public and businesses about the enduring advantages of green technologies. By enhancing understanding and providing financial backing for R&D, middle-income countries' governments can stimulate a transition towards sustainable practices, ensuring future generations benefit from green innovation.

Conclusion

This paper presents the evidence that the relationship between environmental taxes and green technological innovation is U-shaped by using a cross-country panel data analysis of middle-income countries, employing the PMG-ARDL approach. Specifically, negative effects are garnered in the short run, then after crossing the threshold, long-run positive effects are shown. In addition, in the short term, both GDP and R&D do not show explicit association with environmental-related technological innovation while all 3 factors including GDP, R&D and environmental tax affect technology innovation in the long run. The finding provides empirical validation of the statements from prior studies and provides new insights into the role of environmental tax in green technological development among developing countries. Drawing upon the results identified in this study, policy implications are further suggested to leverage the impact of environmental taxation on green technological innovation.

Finally, despite the important results that have been yielded, it is essential to recognize certain limitations for future research. Firstly, due to data unavailability, only 13 middle-income countries are examined in this study. Therefore, further research needs to encompass additional middle-income nations over extended periods as data becomes available to ensure a more comprehensive analysis on the relationship between environmental tax and environmental-related technological innovation. Secondly, as previously mentioned, the effectiveness of environmental taxes in fostering green technological advancements hinges upon the tax rate. While this study has confirmed the influence of environmental taxes on green technological innovation, it has not yet determined the optimal tax rate for studied countries. Hence, further in-depth investigation on individual middle-income countries should be taken to ascertain the ideal tax rate for promoting green technological development. Lastly, pollution level, market competition, education, cultural norms, and other moderating factors could be taken into consideration in further research to contribute to a more comprehensive and robust understanding of the subject matter.

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