

R&D Expenditures and the Pollution Haven Hypothesis: Moderating Effects on MNE Emissions in Developed and Developing Countries

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ABSTRACT

The Pollution Haven Hypothesis (PHH) suggests that multinational enterprises (MNEs) relocate dirty production to countries with lax environmental regulation. However, empirical evidence remains ambiguous, highlighting the role of mediating factors. This study econometrically evaluates the link between MNE activity and greenhouse gas emissions across 76 countries and 41 industries (2000–2020). Using OECD data, we analyze the moderating role of technological development, specifically proxied by R&D expenditures. Results indicate that MNEs are generally less carbon-intensive than domestic firms. In developed countries, combining environmental taxation with R&D significantly reduces emissions. The study concludes that R&D mitigates PHH only when paired with market-based instruments (taxes) rather than command-and-control measures (fees). The study concludes that R&D mitigates PHH only within robust institutional contexts.

Keywords: Pollution, multinational enterprises (MNEs), environmental regulation, greenhouse gas emissions, R&D expenditures.

Mathematics Subject Classification: 62P12

Journal of Economic Literature (JEL) Classification Number: O32, Q53, F18, C55

1. INTRODUCTION

The global transition toward clean energy has accelerated dramatically in recent years, driven by the urgent need to mitigate climate change and the increasing cost-competitiveness of renewable sources such as solar, wind, and hydropower. While technological advancements have reduced the levelized cost of energy (LCOE) for renewables, the primary challenge remains the decarbonization of existing industrial bases and the prevention of carbon leakage. As nations strive to meet the targets of the Paris Agreement, the role of Multinational Enterprises (MNEs) becomes pivotal. MNEs are the primary vectors for international technology transfer, possessing the capital and R&D capacity to deploy clean

energy solutions globally. However, the environmental impact of these investments is not uniform; it is heavily contingent on the regulatory frameworks of host countries.

The central concern in this context is the Pollution Haven Hypothesis (PHH), which posits that stringent environmental regulations in developed economies may drive carbon-intensive industries to relocate to jurisdictions with laxer standards. If true, this dynamic could undermine global clean energy efforts by merely shifting emissions rather than reducing them. Conversely, if MNEs act as conduits for "green" technologies, they could transform developing economies into "green havens." The empirical evidence on this dichotomy remains ambiguous, suggesting that the outcome depends on mediating factors, particularly technological development (R&D) and the design of environmental policy instruments.

This study addresses a critical gap in the literature by examining how R&D expenditures moderate the relationship between MNE activity and greenhouse gas (GHG) emissions across different institutional contexts. While previous studies have broadly analyzed technology transfer, few have disentangled the specific effects of R&D intensity when combined with distinct regulatory tools—namely, environmental taxes versus fines. This distinction is vital for clean energy engineering policy: taxes provide predictable price signals that incentivize long-term R&D in clean technologies, whereas fines may act as short-term operational costs that fail to stimulate innovation.

Using a balanced panel dataset covering 76 countries and 41 industries from 2000 to 2020, we econometrically evaluate whether R&D mitigates the pollution haven effect or exacerbates it through a "green paradox." Our analysis reveals a stark heterogeneity: in developed economies with robust institutions, the combination of environmental taxation and high R&D significantly reduces emissions, supporting the clean energy transition. In contrast, in developing economies relying on fines, higher R&D is paradoxically associated with increased emissions, suggesting that technology is being used to intensify rather than clean up production.

The remainder of this paper is organized as follows. Section 2 reviews the theoretical genesis of the PHH and the dual role of technology. Section 3 details the data sources, econometric methodology, and empirical results. Section 4 concludes with policy recommendations for fostering genuine clean energy collaboration between developed and developing nations.

2. GENESIS AND CRITIQUE OF THE POLLUTION HAVEN HYPOTHESIS

The canonical Pollution Haven Hypothesis (PHH) posits that countries with lax environmental regulations attract "dirty" industries from stricter jurisdictions, becoming "havens" within global trade. Theoretically grounded in the Heckscher-Ohlin and Stolper-Samuelson frameworks, this logic was expanded by the "North-South" model, which suggests that stringent regulations in developed nations ("North") drive resource-intensive industries to the "global South" where environmental assimilation is treated as a comparative advantage.

However, empirical evidence has challenged these theoretical provisions. Numerous studies found no significant correlation between regulatory strictness and Foreign Direct Investment (FDI) flows. Furthermore, Multinational Enterprises (MNEs) often employ cleaner technologies than local firms due to scale effects and reputational risks. The analysis is complicated by the endogeneity of environmental policy: strictness is determined by income levels and institutional quality, making it difficult to isolate the regulation effect from other economic advantages.

Research has subsequently shifted towards understanding the heterogeneity of PHH. The effect is non-linear and dependent on mediators such as human capital and absorptive capacity. For instance, FDI increased environmental damage in Chinese provinces with low human capital but reduced pollution in developed regions via technology transfer. Positive spillover effects are thus contingent on sufficient institutional and financial development. Additionally, the impact varies by industry specificity (e.g., steel, chemicals) and regional granularity, creating internal pollution havens that complicate country-level aggregation.

Consequently, the discourse has evolved from questioning PHH's existence to identifying the conditions of its manifestation. A key shift is the concept of "Green Havens" regions with high-quality human capital that attract clean, high-tech investments, effectively inverting the PHH logic. International regimes like the Paris Agreement further facilitate low-carbon technology transfer. While Industry 4.0 technologies enhance efficiency and may reduce localization costs based on environmental factors, they also risk locking developing nations into low-tech roles without adequate infrastructure. Modern consensus emphasizes that regulatory quality and innovation incentives matter more than mere strictness; market-based instruments can stimulate modernization rather than just imposing costs. Thus, the current view recognizes a pluralism of scenarios: technologically weak jurisdictions may act as classic havens, while advanced "green havens" attract modernizing investments, making the technological factor a critical but ambiguous moderator.

3. R&D AS A MODERATING FACTOR

Early discourse on PHH was characterized by technological determinism, rooted in the Environmental Kuznets Curve. Neoclassical theories postulated technological progress as an endogenous mechanism to mitigate the environmental costs of relocation, viewing eco-efficiency innovations as a guarantee for integration into global value chains. It was assumed that technology transfer from developed to developing economies would inherently neutralize environmental costs through superior standards.

However, recent empirical studies reveal significant variability in this thesis. Panel data analyses indicate that the effect of technology transfer is heterogeneous, depending on the recipient's initial technological level and the nature of transferred technologies. Consequently, technological progress can either mitigate or exacerbate PHH. In high-income countries, rising R&D expenditures correlate with reduced carbon intensity, supporting the mitigation scenario where technology drives

environmental modernization. Developed nations focus on clean technologies and energy efficiency, a phenomenon known as "induced innovation," where strict regulation stimulates eco-friendly progress. This aligns with the Porter-Linde hypothesis, suggesting that well-designed norms enhance long-term competitiveness through innovation rather than causing capital flight.

Paradoxically, studies confirm a positive link between R&D expenditures and CO₂ growth in middle- and low-income countries. Here, technology often serves to intensify existing carbon-heavy processes rather than replace them, leading to a "green paradox" where efficiency gains increase overall environmental pressure. In the absence of strict regulations and green incentives, innovations are directed towards cost reduction and output expansion in dirty sectors. Thus, without the "absorptive capacity" to implement green solutions, technology becomes a tool for PHH, enhancing the profitability of polluting productions.

In summary, the role of technology is derivative of the institutional context. It mitigates PHH where robust institutions and green demand exist, realizing the potential of "climate capitalism". Conversely, it exacerbates PHH where global specialization locks countries into dirty industries, limiting the prospects for genuine ecological modernization. Therefore, this study hypothesizes that the moderating role of technological development (proxied by R&D) in mitigating PHH is conditional on the economic development level of the host economy.

4. DATA AND VARIABLES

The empirical analysis relies on a balanced panel dataset covering 76 countries and 41 industries (ISIC classification) over the period 2000–2020. Greenhouse gas emissions (EMIS) are drawn from the OECD Greenhouse Gas Footprint Indicators, while environmental policy instruments, specifically the counts of active taxes (TAX) and fees (FEE), are sourced from the OECD Policy Instruments for the Environment (PINE) database. Data on multinational enterprise (MNE) activity are obtained from the OECD Analytical Activities of MNEs (AAMNE) database, which distinguishes between foreign-controlled and domestic firms based on a 50% ownership threshold. Specifically, FGO and DGO represent the gross output of foreign-controlled and domestic enterprises, respectively, while FGVA and DGVA denote their corresponding value added; these metrics allow for a granular assessment of production scale versus economic contribution. Additionally, trade openness (TO) is included as a control variable to account for global market integration. Technological development is proxied by RD, defined as gross domestic expenditure on R&D as a percentage of GDP, sourced from the World Bank DataBank.

To estimate the impact of these factors on emissions, we employ a multidimensional fixed effects panel model that includes country, year, and industry fixed effects, with all monetary and emission variables log-transformed to reduce variation. The core specification introduces interaction terms,

such as the triple interaction between MNE activity, regulatory instruments, and R&D, to explicitly test the moderating role of technological development under different regulatory regimes.

5. EMPIRICAL RESULTS

The baseline estimation results confirming the relationship between greenhouse gas emissions and the economic activity of foreign and domestic firms are omitted here to conserve space but are available upon request. These findings align with theoretical expectations: both gross output (DGO, FGO) and value added (DGVA, FGVA) for both domestic and foreign entities exert a statistically significant positive impact on emission volumes (lnEMIS). However, the coefficients associated with MNEs (lnFGO, lnFGVA) are notably smaller than those for domestic firms (lnDGO, lnDGVA), indicating that MNEs generate fewer emissions per unit of output or value added compared to local companies. Furthermore, variables reflecting the share of MNEs in total output (SF_GO) and value added (SF_GVA) demonstrate a statistically significant negative effect on emissions. Specifically, a one percentage point increase in the share of MNEs in the economy is associated with an approximate 1% reduction in emissions, supporting the thesis that MNEs contribute to lowering the carbon intensity of host economies. Finally, both environmental taxes (TAX) and fees (FEE) exhibit a statistically significant restraining effect on emissions, while economic openness is positively correlated with emissions in most specifications, likely reflecting a scale effect driven by international trade.

The core findings, however, emerge from the subsample analysis distinguishing between developed and developing economies (Table 1), which reveals a stark heterogeneity in the moderating role of R&D.

In developed countries, the triple interaction term between MNE activity, environmental taxes, and R&D expenditures ($\ln FGO \times TAX \times RD$) exhibits a negative and statistically significant coefficient. This suggests that in mature economies, the synergy between market-based tax instruments and high technological capacity effectively drives emission reductions. Other interaction terms involving fees or double interactions remain statistically insignificant, indicating that environmental taxes are the primary policy lever reinforcing the green impact of R&D in these jurisdictions.

In contrast, the picture in developing countries is markedly different. Here, the interactions involving environmental fees and R&D dominate the results. Specifically, the triple interaction term between MNE activity, fees, and R&D ($\ln FGO \times FEE \times RD$) shows a positive and statistically significant effect. This implies that in developing economies, combining fines with technological advancement paradoxically correlates with increased emissions. This may indicate the inefficiency of fee-based regulations or suggest that technology is being directed towards intensifying production in polluting sectors rather than abatement, as other interactions (including those with taxes) remain statistically insignificant.

Table 1: The role of R&D in exacerbating or mitigating the Pollution Haven Hypothesis effect.

Countries	All	Developing	Developed	All	Developing	Developed
Variables	lnEMIS	lnEMIS	lnEMIS	lnEMIS	lnEMIS	lnEMIS
lnDGO	0.531*** (0.0529)	0.559*** (0.0807)	0.527*** (0.0638)			
lnFGO	0.192*** (0.0434)	0.169 (0.103)	0.194*** (0.0581)			
lnDGVA				0.483*** (0.0517)	0.538*** (0.0805)	0.472*** (0.0601)
lnFGVA				0.175*** (0.0407)	0.0924 (0.0984)	0.199*** (0.0591)
TO	0.107 (0.151)	0.153 (0.220)	0.0592 (0.172)	0.367** (0.172)	0.436* (0.250)	0.359* (0.189)
TAX	-0.0115 (0.0192)	0.00843 (0.0328)	-0.0639 (0.0418)	-0.0171 (0.0205)	-0.0106 (0.0282)	-0.0635 (0.0388)
FEE	-0.0253 (0.0395)	0.0620 (0.0846)	-0.0236 (0.0508)	-0.0284 (0.0366)	0.0626 (0.0636)	-0.0197 (0.0489)
RD	0.152 (0.161)	0.474 (0.399)	-0.00424 (0.180)	0.173 (0.131)	0.380 (0.350)	0.0686 (0.160)
TAX*RD	0.00380 (0.0117)	-0.0102 (0.0369)	0.0272 (0.0158)	0.00520 (0.0114)	0.00751 (0.0312)	0.0251 (0.0147)
FEET*RD	-0.0142 (0.0348)	-0.0837** (0.0327)	0.0130 (0.0419)	-0.0128 (0.0295)	-0.0786*** (0.0224)	0.0134 (0.0350)
lnFGO*TAX	0.00103 (0.000770)	0.00242 (0.00331)	0.00563 (0.00390)			
lnFGO*RD	-0.0234 (0.0149)	-0.0447 (0.0360)	-0.00702 (0.0203)			
lnFGO*TAX*RD	-0.000565 (0.000702)	-0.00311 (0.00431)	-0.0025* (0.00142)			
lnFGO*FEE	0.00132 (0.00383)	-0.00517 (0.00985)	0.00118 (0.00524)			
lnFGO*FEE*RD	0.00201 (0.00336)	0.0114** (0.00446)	-0.00088 (0.00422)			
lnFGVA*TAX				0.00177* (0.000973)	0.00440 (0.00310)	0.00659 (0.00405)
lnFGVA*RD				-0.0310** (0.0117)	-0.0402 (0.0376)	-0.0206 (0.0198)
lnFGVA*TAX*RD				-0.000783 (0.000737)	-0.00508 (0.00413)	-0.0027* (0.00147)
lnFGVA*FEE				0.00173 (0.00382)	-0.00499 (0.00838)	0.000707 (0.00567)
lnFGVA*FEE*RD				0.00200 (0.00298)	0.0118*** (0.00389)	-0.00106 (0.00370)
Constant	-6.576*** (0.334)	-6.664*** (0.463)	-6.65*** (0.536)	-5.548*** (0.284)	-5.482*** (0.430)	-5.74*** (0.468)
Observations	46,176	16,523	29,653	46,162	16,519	29,643
R-squared	0.877	0.864	0.888	0.871	0.855	0.884

6. DISCUSSION AND CONCLUSION

In conclusion, this study demonstrates that R&D mitigates the Pollution Haven Hypothesis only within robust institutional contexts. The analysis reveals a stark heterogeneity: in developed economies, the synergy between environmental taxes and R&D significantly drives emission reductions. Conversely, in developing economies, the interaction between environmental fees and R&D is associated with

increased emissions, suggesting a 'green paradox' where technology intensifies carbon-heavy processes in the absence of effective market-based incentives. Consequently, the global clean energy transition cannot rely solely on technology diffusion. Policymakers in developing nations must prioritize shifting from unpredictable fines to transparent, market-based tax mechanisms to ensure that foreign investment and technological upgrades contribute to genuine decarbonization.

This research was supported by the Russian Science Foundation (Grant Agreement No. 25-18-00647).

Consistent with current norms of scholarship, we disclose the use of artificial intelligence (OpenAI, 2026) in this work. The application was limited to selective copy editing, conducted under careful human oversight, helping to mitigate the financial constraints associated with professional editing services.

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