



Market-based environmental regulation and competitiveness: A comparative analysis of developed and developing economies

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Abstract:

This study investigates the impact of market-based environmental regulations on industrial performance and innovation across 48 countries (30 developed, 18 developing) from 1995 to 2021. Using environmental taxes, instrumented by lagged CO₂ emissions and women's political empowerment, and public environmental expenditures as a robustness check. The results reveal heterogeneous effects across development levels. Environmental taxes increase productivity and R&D investment in developed economies but have limited impact in developing ones. Public environmental expenditures reduce productivity in both groups while affecting innovation differently. These findings suggest that environmental regulation can promote competitiveness and innovation, but its effectiveness depends on national economic and institutional conditions.

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How to cite this article:

Mansouri R., Tounsi S. (2026), "Market-based environmental regulation and competitiveness: A comparative analysis of developed and developing economies", *PSL Quarterly Review*, 79 (316), pp. 51-69.

DOI: <https://doi.org/10.13133/2037-3643/19048>

JEL codes:

Q55, Q58, O31, O57

Keywords:

Porter Hypothesis, environmental regulation, productivity, innovation, comparative analysis

Journal homepage:

https://rosa.uniroma1.it/rosa04/psl_quarterly_review

Since the 1970s, a growing number of countries have adopted environmental policy instruments, such as carbon taxes, emissions trading schemes, and regulatory standards, to address climate change and promote sustainable development (Hojnik and Ruzzier, 2016; D'Arcangelo et al., 2022;

* We are grateful to Mohammed V University of Rabat, the Faculty of Law, Economics and Social Sciences – Agdal (FSJES-Agdal) and the Laboratory of Applied Economics for their institutional support. We also thank the anonymous reviewers of this paper for their constructive feedback. The usual disclaimer applies.

This research project was conducted with the support of the Centre National pour la Recherche Scientifique et Technique (CNRST). Rim Mansouri is the recipient of the PhD-Associate Scholarship (PASS) awarded by the CNRST.

No potential conflict of interest was reported by the authors.

The data used in this study are publicly available from the World Bank's World Development Indicators database (<https://databank.worldbank.org/source/world-development-indicators>) and the International Monetary Fund's Climate Policy Indicators database (<https://climatedata.imf.org/pages/go-indicators>). All variables, sources, and transformations are described in the manuscript and supplementary materials. Replication files can be provided upon request.



Blanchard et al., 2023). These measures are embedded in major global initiatives such as the Sustainable Development Goals, the Kyoto Protocol, and the Paris Agreement. While these efforts reflect increasing political commitment to environmental protection, they have also sparked debates on the potential trade-offs between regulation and economic competitiveness, particularly in terms of industrial productivity and innovation performance.

Against this backdrop, this paper investigates the economic effects of environmental regulation, focusing on productivity and innovation outcomes across a panel of 48 countries (30 developed and 18 developing) over the period 1995-2021. Our analysis is grounded in the Porter Hypothesis (Porter, 1991; Porter and van der Linde, 1995), which argues that properly designed environmental policies can stimulate innovation and enhance competitiveness rather than hinder it. While the hypothesis has generated substantial empirical interest, evidence remains fragmented, especially regarding differences between developed and developing economies and across types of policy instruments.

This study contributes to this ongoing debate through a comparative and methodological lens. From a comparative perspective, we explicitly examine how development levels condition the effectiveness of market-based environmental policies. While developed economies may benefit from stronger institutional frameworks and greater technological capacity, developing countries often face structural constraints that may limit the benefits of regulation. From a methodological perspective, we address endogeneity concerns by instrumenting our main policy variable, environmental taxes, using lagged per capita CO₂ emissions and women's political empowerment. As a robustness check, we also examine the role of public environmental protection expenditures, capturing a different dimension of regulatory effort.

Three key motivations guide our approach. First, the economic implications of environmental regulations remain underexplored in developing contexts, despite increasing policy adoption and growing environmental challenges (Yang et al., 2012; Rubashkina et al., 2015). Second, integrating environmental considerations into broader development policy can improve policy coherence and help avoid suboptimal trade-offs between growth and sustainability (Ashford and Hall, 2011; de Miranda Ribeiro and Kruglianskas, 2015). Third, environmental regulation affects key macroeconomic variables such as trade, employment, and investment, with direct relevance for policymaking (Dechezleprêtre and Sato, 2017).

Our results show that environmental taxes have a positive and significant effect on productivity in developed economies, particularly when estimated using instrumental variables, suggesting that conventional estimations underestimate the impact due to endogeneity. In contrast, these taxes do not significantly affect productivity in developing countries. Regarding innovation, environmental taxes are associated with a decline in patent filings across countries but they increase research and development (R&D) investment in developed economies. Public environmental expenditures, meanwhile, reduce productivity in both groups but are associated with increased R&D in developed countries and reduced patenting in developing ones.

These findings underscore the importance of policy design and institutional context in shaping the effectiveness of environmental regulation. By highlighting heterogeneity across development levels and distinguishing between policy instruments, this paper contributes to a more nuanced understanding of the economic implications of environmental policy in the context of global sustainability transitions.

The rest of the paper is structured as follows. Section 1 reviews the main empirical studies on environmental regulation and economic performance. Section 2 presents the data and econometric methodology. Section 3 discusses the empirical results. Section 4 concludes with policy implications.

1. The Porter Hypothesis: an overview of empirical studies

The seminal contributions of Michael Porter (1991) and Porter and van der Linde (1995) introduced a novel theoretical framework challenging the traditional view that environmental regulation necessarily hampers industrial performance. According to the Porter Hypothesis, well-designed regulations can foster efficiency and innovation, ultimately enhancing productivity. Jaffe and Palmer (1997) later clarified the hypothesis into three distinct versions: (1) the “narrow” version, which emphasizes the superior effectiveness of market-based instruments; (2) the “weak” version, suggesting that regulation stimulates innovation regardless of productivity outcomes; and (3) the “strong” version, which holds that environmental policies directly improve productivity.

This study contributes to the empirical assessment of all three versions of the hypothesis by providing a comparative analysis across development levels, a perspective that is still underrepresented in the literature.

1.1. The strong version of the Porter Hypothesis: a focus on productivity

Empirical evidence on the link between environmental regulation and productivity remains mixed. Early studies often reported negative impacts, particularly in pollution-intensive industries and during periods of regulatory tightening. For instance, Gollop and Roberts (1983), Barbera and McConnell (1986, 1990), and Gray and Shadbegian (2003) document declines in productivity growth in the United States, largely attributed to rising compliance costs during the 1970s and 1980s.

However, subsequent research has highlighted compensatory mechanisms. Berman and Bui (2001) observe productivity improvements in California oil refineries, while Lanoie et al. (2008) find long-term positive effects in the Quebec manufacturing sector. Theoretical models such as those of Xepapadeas and de Zeeuw (1999) also suggest that regulation can spur capital renewal and technological upgrading, with productivity gains over time.

Recent literature emphasizes the importance of heterogeneity across contexts. Greenstone et al. (2012), for example, report a 4.8% average decline in total factor productivity in highly regulated U.S. states, though effects vary by industry and pollutant. Managi et al. (2005) note that compliance costs in offshore oil production can coexist with environmental efficiency gains.

Some studies focus on cross-country comparisons. Alpay et al. (2002) find that environmental regulation positively impacts productivity in Mexico but negatively in the United States, within the same industrial sector. This suggests that developing economies may benefit more than developed economies from technological catch-up. Moreover, nonlinear effects have been documented: Wang and Shen (2016) identify an inverted U-shaped relationship in China, while Albrizio et al. (2017) highlight short-term gains in productivity following regulation in advanced OECD countries.

1.2. The weak version of the Porter Hypothesis: a focus on innovation

A larger body of evidence supports the “weak” version of the Porter Hypothesis, which posits that environmental regulation stimulates innovation. Pioneering studies by Jaffe and Palmer (1997) and Brunnermeier and Cohen (2003) show increased R&D activity in response to environmental compliance requirements. Subsequent panel studies on OECD firms reinforce this view, linking

regulatory stringency to higher environmental R&D spending (Fronzel et al., 2007; Lanoie et al., 2011).

Sector-specific research also supports this link. Aghion et al. (2016) show that clean vehicle innovation is positively influenced by environmental policy and energy prices. Cael and Dechezleprêtre (2016) find that the EU Emissions Trading Scheme encourages low-carbon technologies, while Zhao et al. (2022) report that environmental taxes promote innovation in Chinese provinces with higher tax burdens. Similar patterns are observed in African contexts, as shown by Manu et al. (2024).

Nevertheless, not all findings are supportive. Long and Wan (2017) and Arimura et al. (2007) detect no significant innovation response, and Feng et al. (2018) report negative effects. These discrepancies highlight the role of contextual factors, such as policy design, firm capabilities, and industry structure. Kneller and Manderson (2012) further suggest a substitution effect, whereby environmental R&D may crowd out conventional innovation.

1.3. Joint testing of the strong and the weak versions

Only a limited number of studies jointly assess the productivity and innovation effects of regulation, yet these are particularly relevant for understanding the mechanisms underpinning the Porter Hypothesis. Hamamoto (2006), for instance, analyzes five Japanese manufacturing industries and finds that environmental regulation increases both R&D investment and productivity via technological upgrading.

Yang et al. (2012) observe similar dynamics in Taiwan's manufacturing sector: pollution abatement expenditures are associated with higher R&D, and innovation mediates positive productivity outcomes. Lanoie et al. (2011) confirm that perceived regulatory pressure fosters innovation, which in turn enhances firm performance in seven OECD countries. Rubashkina et al. (2015), using an instrumental variable strategy, find a positive effect of regulation on patenting in European manufacturing, though no significant productivity gains, pointing to a partial validation of the Porter Hypothesis. Franco and Marin (2017) further refine this analysis by distinguishing downstream and intra-sectoral policies in eight European countries. They find that downstream regulation boosts both innovation and productivity, while intra-sectoral regulation enhances only the latter. This distinction suggests that different policy designs may trigger distinct mechanisms.

1.4. The narrow version: the role of market-based instruments

The "narrow" version of the hypothesis argues that market-based instruments, such as environmental taxes or tradable permits, are more effective than command-and-control regulations in fostering innovation. These instruments provide greater flexibility and cost-efficiency, allowing firms to adjust their strategies and invest in cleaner technologies. Empirical studies generally support this claim. Burtraw (2000) shows that the U.S. SO₂ (sulfur dioxide) emissions trading program significantly reduced compliance costs. Johnstone and Labonne (2006) find that environmental taxes are positively linked to R&D, while rigid standards may constrain innovation. However, findings are not universally favorable. Popp (2003) and Taylor (2012) document declines in innovation after the introduction of certain cap-and-trade schemes. Rexhäuser and Rammer (2014) highlight that only innovations focused on resource efficiency translate into higher profitability, especially when driven by regulation rather than market demand.

Taken together, these empirical studies suggest that the effectiveness of environmental regulation, whether in terms of productivity or innovation, depends heavily on the type of policy instrument, the level of economic development, and the institutional context. A complementary body of work on the political economy of environmental taxation argues that institutional capacity, such as the administrative ability to measure and enforce emissions, shapes both the adoption and the stringency of market-based instruments (Levi et al., 2020; Dolphin et al., 2020). In settings with stronger regulatory framework, environmental taxes are more likely to generate support for clean R&D, which increases the scope for Porter-type productivity and innovation gains (Carattini et al., 2018). By contrast, in weaker institutional environments, environmental taxes may be poorly enforced or highly volatile, limiting firms' incentives to undertake long-term innovation. This paper addresses these gaps by providing a global comparative test of the Porter Hypothesis, with a particular focus on environmental taxes and public expenditures, using an instrumental variable strategy to explore heterogeneity across development levels and institutional contexts.

2. Data sources and empirical strategy

The objective of this section is to estimate the impact of environmental regulation on productivity and innovation across 48 countries, distinguishing between developed and developing economies over the period 1995-2021. This classification reflects both structural differences between the two groups and the specific challenges they face in advancing sustainable development. Furthermore, given that some large middle-income economies may not fit neatly into this binary classification, we later assess robustness to excluding China, Brazil, and Turkey (see section 3.2.1). We also distinguish between two types of market-based environmental regulations: environmental taxes and public expenditures on environmental protection.

After applying a logarithmic transformation to linearize the relationships, we estimate the following panel model:

$$Y_{it} = \alpha_{it} + \beta_0 \cdot RE_{it} + \beta_n \cdot X_{it} + \varepsilon_{it}$$

where i represents the country index, t the time dimension, and n the number of control variables. The dependent variable Y_{it} captures economic performance, proxied by productivity and innovation indicators. RE_{it} is the matrix of market-based environmental regulation indicators, measured by environmental taxes and public environmental expenditures. X_{it} denotes the matrix of control variables, and ε_{it} is the error term.

2.1. Presentation of the variables

2.1.1. *Dependent variables: productivity and innovation*

Economic performance is assessed using two key indicators, productivity and innovation, sourced from the World Bank's World Development Indicators (World Bank, 2024). Productivity is measured by log-transformed real *value added in the manufacturing sector*, which reflects the net contribution of manufacturing to GDP, adjusted for inflation. Innovation is proxied by two complementary indicators: (i) the share of public *R&D expenditures* in GDP, and (ii) the number of *patent applications* (log-transformed). These variables are widely recognized in the literature as

reliable proxies for both the inputs (R&D intensity) and outputs (patent activity) of innovation processes (Jaffe et al., 2000).

2.1.2. *Independent variables: environmental regulation*

We use two main indicators to represent market-based environmental regulation. First, *Environmental taxes*, expressed as a percentage of GDP, are drawn from the IMF's Climate Policy Assessment Tool (International Monetary Fund, 2024). These taxes are defined as levies imposed on goods or services with negative environmental impacts. A higher tax share indicates more extensive use of green fiscal instruments to discourage polluting behavior and internalize environmental externalities. Second, *Public environmental protection expenditures*, measured in national currency and as a percentage of GDP, are sourced from the IMF's Government Finance Statistics (GFS) (International Monetary Fund, 2024). These expenditures reflect direct budgetary allocations toward environmental objectives. They may include subsidies, infrastructure investments (e.g., wastewater treatment plants), public awareness campaigns, or funding for research in green technologies.

These two variables embody distinct forms of government intervention. *Environmental taxes* rely on price signals and follow the "polluter pays" principle, aiming to modify behavior while raising public revenues. *Public expenditures*, by contrast, constitute direct fiscal outlays by the state, with potentially redistributive or capacity-building effects, but do not necessarily affect market prices.

2.1.3. *Control variables*

Based on the empirical literature, we include the following controls:

- i) *Human capital*, proxied by gross tertiary enrollment rates, reflects a country's capacity to adopt and generate innovation (World Bank, 2024).
- ii) *Investment*, captured by gross fixed capital formation as a percentage of GDP, represents a key driver of long-term productivity and infrastructure development (World Bank, 2024).
- iii) *Labor force size*, measured as the total economically active population (log-transformed). While a growing labor force can enhance output, it may also generate environmental and infrastructural pressures in low-income countries (World Bank, 2024).
- iv) *Inflation*, defined as the annual change in the consumer price index (CPI), is included to account for macroeconomic instability, which may affect both private investment and public spending priorities.

2.2. Descriptive statistics

Table 1 presents summary statistics for the variables used in our empirical models, for the full sample as well as disaggregated by development level (developed vs. developing countries). Clear disparities emerge between the two groups. Developing countries exhibit higher inflation rates on average, while developed economies display significantly higher tertiary enrollment rates, indicative of more advanced human capital. Differences in other variables, such as gross fixed capital formation, manufacturing value added, patent applications, environmental taxation, and public environmental expenditures, are less pronounced but they still reflect structural

heterogeneities across income levels. Detailed statistics, including the number of observations, mean, standard deviation, minimum, and maximum values for each variable, are provided in the appendix.

Table 1 – *Descriptive statistics*

Variable	Full sample	Developed countries	Developing countries
Labor	15.746	15.287	16.513
Investment	24.574	24.901	23.983
Value added – manufacturing sector	24.148	24.384	23.707
R&D expenditures	1.5	1.862	0.691
Patent applications	7.892	7.826	8.017
Environmental tax	23.442	23.296	23.801
Environmental protection expenditures	22.054	21.795	22.867
Education	56.558	65.629	41.157
Inflation	5.479	2.601	10.275

2.3. Instrumental variable to address endogeneity

2.3.1. *Sources of endogeneity*

Given the nature of our research question and the structure of the panel data, we rely on an instrumental variables (IV) approach to address potential endogeneity concerns. One source of endogeneity arises from unobserved country-specific factors that may simultaneously affect a country's level of productivity and the stringency of its environmental regulations. While the use of panel data allows us to control for such unobserved heterogeneity through fixed effects, it does not fully eliminate simultaneity bias. A second, and arguably more critical, source of endogeneity is reverse causality. In empirical analyses of the Porter Hypothesis, environmental regulation is typically treated as exogenous. However, more productive economies may also be better positioned to implement stricter environmental policies, due either to stronger institutions or greater fiscal capacity (Eliste and Fredriksson, 2002; Cole et al., 2006; Levinson and Taylor, 2008). Conversely, countries with large polluting sectors may face strong political resistance to regulatory tightening.

2.3.2. *Selection and validity of instruments*

The instruments selected in our empirical strategy must satisfy both the relevance condition and the exclusion restriction associated with the instrumental variables (IV) approach. In our model, we instrument only one market-based environmental regulation variable: the *environmental tax*. We use two instruments: (i) *per capita CO₂ emissions* lagged by five years, and (ii) *women's political power*, measured by the percentage of seats held by women in a country's lower or single house of parliament.

Both instruments display strong predictive power for the intensity of environmental taxation. Countries with historically higher emissions tend to face greater domestic and international pressure to adopt stricter market-based environmental tools. Lagged emissions capture this long-term regulatory inertia: tax reforms rarely occur in isolation but build on previous environmental performance and industrial trajectories. Similarly, a well-established literature documents that women consistently express stronger pro-environmental preferences and are more supportive of public environmental action (McCright, 2010). These attitudes translate into political behavior, where higher female representation is associated with a greater likelihood of the adoption of environmental policies. Consistent with these arguments, the first-stage results confirm that both instruments are statistically strong predictors of environmental tax intensity.

The key identifying assumption is that neither lagged emissions nor women's parliamentary representation affect productivity and innovation except through their influence on environmental tax policy, once relevant controls are included. To mitigate concerns that emissions may correlate with current industrial performance, we use a five-year lag, which limits direct contemporaneous channels such as energy efficiency improvements and short-run cyclical fluctuations. This approach is consistent with earlier empirical work exploiting predetermined environmental conditions to instrument contemporary regulation.

For women's representation, we acknowledge that broader governance improvements could be a potential channel. We therefore include a wide set of institutional and socioeconomic controls to absorb these alternative mechanisms. Moreover, the tests of overidentifying restrictions do not reject the joint validity of the instruments, and the first-stage F-statistics are comfortably above conventional thresholds, indicating that the instruments are not weak.

Nonetheless, we recognize that the exclusion restriction cannot be proven statistically, and we discuss potential threats more explicitly. Emissions intensity may influence industrial structure in ways unrelated to environmental taxation, and female political empowerment may correlate with broader reformist agendas. These caveats are acknowledged in the discussion section, and we show that the main results remain stable when relaxing the identifying assumptions through alternative specifications and robustness checks.

Finally, we instrument only the environmental tax variable. Public environmental expenditures are kept in the robustness analysis without instrumentation to avoid adding instruments that would be difficult to justify convincingly and risk overfitting the first stage.

3. Empirical estimation results: market-based environmental regulation

3.1. Environmental tax

Table 2 presents the estimated impact of environmental taxes on productivity using both fixed-effects models (columns 1 to 3) and instrumental variable (IV) estimations (columns 4 to 6). Models (1) through (3) correspond to the full sample, developed countries, and developing countries, respectively. The fixed-effects estimates reveal a positive and statistically significant effect of environmental taxes on productivity for the full sample (coefficient = 0.041) and for developed countries (coefficient = 0.192). In contrast, the effect is slightly negative and statistically insignificant for developing countries (coefficient = -0.008). These findings suggest that environmental taxes may serve as incentives for productivity improvements, particularly in advanced economies.

When applying the IV approach, using lagged per capita CO₂ emissions and women's political representation as instruments, the estimated effect strengthens for the full sample (model 4) and developed countries (model 5), while remaining insignificant for developing countries (model 6). This pattern indicates that the initial estimates may have been biased by endogeneity and that productivity gains from environmental taxation are mainly concentrated in countries with more developed institutional and technological capacities. Statistical diagnostics support the validity of the instruments employed. The first-stage F-statistics exceed the conventional threshold of 10, ruling out weak instrument concerns. Additionally, the Sargan overidentification test does not reject the exclusion restrictions, confirming the instruments' validity and their independence from the error term in the structural equation.

Regarding control variables, both education and investment show positive and statistically significant effects across fixed-effects and IV models. Conversely, labor force size and inflation exhibit significant negative effects in the IV models, particularly for labor in models (4) and (5), and for inflation in model (4).

Table 2 – Estimation result of the effect of an environmental tax on productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	FE1	FE2	FE3	IV1	IV2	IV3
Env. tax	0.041*** (0.014)	0.192*** (0.032)	-0.008 (0.015)	0.136*** (0.032)	0.288*** (0.069)	0.030 (0.043)
Labor	-0.054 (0.079)	-0.090 (0.098)	0.234* (0.119)	-0.390*** (0.088)	-0.485*** (0.106)	-0.091 (0.139)
Investment	0.501*** (0.029)	0.407*** (0.037)	0.536*** (0.049)	0.530*** (0.032)	0.499*** (0.043)	0.580*** (0.064)
Education	0.005*** (0.001)	0.003*** (0.001)	0.004*** (0.001)	0.003*** (0.001)	0.002 (0.001)	0.003*** (0.001)
Inflation	-0.001 (0.001)	-0.002 (0.003)	-0.001 (0.001)	-0.006*** (0.001)	-0.004 (0.003)	-0.002 (0.002)
Constant	11.381*** (1.010)	10.790*** (1.320)	7.190*** (1.497)			
Observations	820	607	213	687	496	191
Overall R-squared	0.907	0.833	0.941	0.631	0.560	0.797
First-stage F				87.966	54.610	16.204
Sargan J				6.252	1.595	1.766

Notes: *t* statistics are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3 examines the effect of environmental taxes on innovation, distinguishing between patent applications (models 1 to 3) R&D expenditures (models 4 to 6). The models are estimated for the full sample, developed countries, and developing countries, respectively.

The results for patent applications consistently indicate a negative impact of environmental taxes across all subsamples, with coefficients of -0.100 (model 1), -0.785 (model 2), and -0.135 (model 3). The effects are statistically significant in models (2) and (3), suggesting that environmental taxes may reduce patenting activity, especially in developed countries. This decline could reflect short-term cost pressures or a resource reallocation away from formal innovation activities. In contrast, the findings for R&D expenditures are more nuanced. Model (5), covering developed countries, shows a positive and statistically significant effect (a coefficient of 0.256), whereas the other models do not exhibit significant effects. This implies that, in advanced economies, environmental taxes might encourage ex ante innovation efforts through increased R&D investment, even if these efforts do not immediately translate into patent output. Control variables show that labor force participation is positively and significantly associated with innovation in most models, while investment displays a negative effect on patent applications in some cases but a positive effect on R&D in others. Education consistently has a positive and significant impact, whereas inflation tends to have a negative effect on patenting.

Table 3 – Estimation result of the effect of an environmental tax on innovation

	(1)	(2)	(3)	(4)	(5)	(6)
	Patents	Patents	Patents	R&D	R&D	R&D
Env. tax	-0.100 (-1.96)	-0.785^{***} (-6.87)	-0.135^{***} (-3.69)	0.0237 (0.84)	0.256^{***} (4.20)	-0.0240 (-1.29)
Labor	1.770^{***} (6.34)	0.973^{**} (2.82)	1.746^{***} (5.76)	0.210 (1.24)	0.168 (0.81)	0.805^{***} (4.64)
Investment	-0.554^{***} (-5.12)	-0.284^* (-1.99)	-0.0238 (-0.19)	0.0127 (0.23)	-0.133 (-1.84)	0.240^{***} (3.86)
Education	-0.00163 (-0.87)	0.00413 (1.70)	0.00926^{***} (4.00)	0.0112^{***} (10.33)	0.0110^{***} (7.43)	0.00224 (1.97)
Inflation	-0.00802^{**} (-2.93)	-0.0223^* (-2.58)	-0.00343 (-1.97)	-0.000295 (-0.20)	0.00730 (1.29)	-0.000891 (-1.11)
Constant	-3.755 (-1.01)	17.79^{***} (3.80)	-17.76^{***} (-4.38)	-3.262 (-1.43)	-4.146 (-1.45)	-18.17^{***} (-7.03)
Observations	756	565	191	711	542	169

Notes: *t* statistics are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.2. Robustness check

To further evaluate the robustness and sensitivity of our findings, we conduct two types of alternative estimations. The first set of estimations deals with potential concern regarding the binary classification of countries into “developed” and “developing”. To ensure that the main findings are not driven by these outliers, we re-estimate the main baseline regressions after excluding China, Brazil, and Turkey from the sample. These countries do not fit neatly into the conventional “developing” category, and their regulatory and innovation systems are more similar to those of advanced economies than to those of low-income countries. For the second set of estimations, we use a different environmental regulation variable with public environmental protection expenditures. This approach allows us to determine whether the observed effects are specific to the instrumentation strategy applied to environmental taxes or reflect broader impacts of environmental policy interventions.

3.2.1. Sensitivity analysis for the “developing” countries sample (excluding outliers)

The results, reported in table 4, are very similar to the baseline estimates. The coefficients on environmental taxes remain small and statistically insignificant in all three specifications (−0.004 for productivity, 0.005 for patents, and 0.016 for R&D), and their magnitudes are close to zero. This exercise suggests that the main conclusions on the limited Porter-type effects of environmental taxation in developing countries are not sensitive to the exclusion of these large middle-income economies.

Table 4 – Results of the main estimation for developing countries without outliers

	(1) Productivity	(2) Patents	(3) R&D
Env. tax	−0.004 (0.022)	0.005 (0.048)	0.016 (0.030)
Labor	0.254** (0.126)	1.411*** (0.270)	0.678*** (0.192)
Investment	0.476*** (0.055)	0.190 (0.121)	0.285*** (0.074)
Education	0.009*** (0.002)	−0.015*** (0.004)	−0.001 (0.002)
Inflation	−0.006*** (0.002)	−0.003 (0.003)	−0.003 (0.002)
Constant	7.968*** (1.504)	−19.458*** (3.468)	−17.779*** (2.702)
Observations	181	159	138
Overall R-squared	0.900	0.430	0.062

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.2.2. Productivity

Table 5 reports the fixed-effects estimates of the impact of public environmental protection expenditures on productivity for the full sample, developed countries, and developing countries, respectively (models 1 to 3). The coefficients for environmental protection expenditures are negative and statistically significant at the 10% level across all three samples, with values of -0.033 , -0.039 , and -0.031 , respectively. These results contrast with the positive effect found for environmental taxes, indicating that increased public spending on environmental protection may be associated with a decline in productivity.

This divergence could be explained by several factors. First, there is a fundamental difference between fiscal incentives, such as environmental taxes, which use price signals to modify behavior, and direct public expenditures, which may involve significant upfront costs or inefficiencies. Second, residual endogeneity could persist in public spending variables due to potential reverse causality or omitted variables. Third, the timing of economic effects may differ, with expenditures having longer-term or lagged impacts that are not fully captured within our study period.

Regarding control variables, investment and education maintain a positive and statistically significant relationship with productivity in all models, while inflation exhibits a negative and significant effect in the full sample and the developed countries sample (models 1 and 2).

Table 5 – Estimation results of the effect of environmental protection expenditures on productivity

	(1)	(2)	(3)
	FE1	FE2	FE3
Env. prot. exp.	-0.033^{**} (0.015)	-0.039^* (0.023)	-0.031^* (0.019)
Labor	-0.120 (0.081)	-0.135 (0.094)	-0.039 (0.163)
Investment	0.586^{***} (0.028)	0.588^{***} (0.032)	0.610^{***} (0.055)
Education	0.005^{***} (0.001)	0.006^{***} (0.001)	0.003^{***} (0.001)
Inflation	-0.005^{***} (0.001)	-0.007^{***} (0.002)	-0.002 (0.002)
Constant	11.973^{***} (1.092)	12.180^{***} (1.242)	10.375^{***} (2.266)
Observations	808	625	183
Overall R-squared	0.875	0.924	0.916

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.2.3. Innovation

Table 6 examines the relationship between public environmental protection expenditures and innovation, measured by patent applications (models 1 to 3) and R&D expenditures (models 4 to 6). The fixed-effects regressions indicate mostly negative associations between public environmental spending and patent activity, with coefficients of -0.0743 , -0.156 , and -0.0986 for the full sample, developed, and developing countries, respectively. Notably, the negative effect is statistically significant at the 1% level only for developing countries (model 3), suggesting that increased environmental spending may be linked to reduced patenting activity in these contexts.

The analysis of R&D expenditures reveals more nuanced results. Public environmental expenditures positively and significantly influence R&D in developed countries (coefficient = 0.0935 , model 5), while they have a negative effect in developing countries (coefficient = -0.0506 , model 6). No statistically significant relationship is observed in the full sample.

These findings underscore the heterogeneous dynamics of environmental policy effects on innovation across development levels. Developed economies appear more capable of leveraging public environmental expenditures to foster innovation activities, particularly R&D, whereas in developing countries such expenditures may crowd out private innovation efforts or redirect resources away from patent-generating activities.

Table 6 – Estimation results of the effect of environmental protection expenditures on innovation

	(1)	(2)	(3)	(4)	(5)	(6)
	Patents	Patents	Patents	R&D	R&D	R&D
Env. prot. exp.	-0.0743 (-1.51)	-0.156 (-1.94)	-0.0986** (-2.96)	-0.00284 (-0.11)	0.0935* (2.33)	-0.0506* (-2.24)
Labor	1.167*** (4.25)	0.957** (2.95)	2.221*** (7.23)	0.152 (0.93)	0.00171 (0.01)	1.074*** (3.87)
Investment	-0.625*** (-6.43)	-0.838*** (-6.85)	-0.0617 (-0.63)	0.0644 (1.28)	-0.0338 (-0.55)	0.360*** (5.22)
Education	-0.00303 (-1.62)	-0.00347 (-1.48)	0.0000524 (0.03)	0.0112*** (10.48)	0.0123*** (9.50)	-0.000429 (-0.27)
Inflation	0.00761 (1.55)	-0.00152 (-0.19)	0.00560 (1.64)	-0.00429 (-1.44)	0.000690 (0.14)	0.000163 (0.06)
Constant	6.627 (1.74)	17.22*** (3.86)	-25.23*** (-5.76)	-3.070 (-1.35)	-0.265 (-0.11)	-24.96*** (-5.66)
Observations	759	583	176	708	554	154

Notes: *t* statistics are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

This study separates two market-based environmental policy instruments, environmental taxes and public environmental protection expenditures, and compares their effects on productivity and innovation across developed and developing economies. The results offer partial support for the Porter Hypothesis, but effects differ by instrument and by institutional context.

4.1. Environmental tax

Our results show that environmental taxes have a positive and statistically significant effect on productivity in developed countries (0.192) and, to a lesser extent, in the full sample (0.041). In contrast, no significant relationship is observed in developing countries. Regarding innovation, environmental taxation appears to negatively affect patent applications in both developed and developing countries. However, it is positively associated with public R&D spending in developed economies.

These patterns align with the induced innovation view originating with Hicks (1932) and extended in environmental economics. By raising the relative price of pollution-intensive inputs, taxes redirect firms' searches toward cleaner and resource-saving techniques. In settings with strong institutions and technological readiness, this reoptimization appears quickly as process improvements and organizational efficiency that raise measured productivity. The divergence between R&D and patents can be understood along three lines. First, taxes tend to encourage process change that firms often protect through secrecy, learning-by-doing, and complementary capabilities rather than formal patenting, so patent counts understate innovative effort. Second, R&D spending adjusts faster than patent outputs because patenting involves longer and more uncertain lags; in short panels or contemporaneous specifications, the data can show a positive R&D response with flat or negative patent counts. Third, when taxes are perceived as cost shocks under policy uncertainty, firms reallocate from patent-intensive product R&D to near-term process R&D. Consistent with Goulder and Parry (2008) and Johnstone et al. (2010), broad-based taxes are not designed to target innovation incentives in the way R&D subsidies are, and their innovative impact depends on policy credibility and enforcement quality. As Porter and van der Linde (1995) argue, credible and well-signaled regulation is more likely to induce cost-saving technological upgrading; weak or volatile signals are not.

Heterogeneity in tax rates, bases, exemptions, and enforcement also helps explain mixed outcomes. Designs with broad coverage, limited carve-outs, and predictable trajectories create clearer incentives and make productivity gains more likely in contexts where complementary assets are available.

4.2. Market-based environmental regulations: environmental protection expenditures

Public environmental protection expenditures are associated with lower productivity in the full sample and in both income groups. Their innovation effects are heterogeneous; they correlate positively with R&D in developed economies but are linked to lower patenting in developing countries. A compositional and institutional interpretation is plausible. A sizable share of these expenditures goes to monitoring, enforcement, remediation, and abatement infrastructure. Such items raise measured costs in the short run, which depresses productivity, while many benefits arrive with long lags or outside firm accounts. In high-income settings, spending that takes the form of research grants, demonstration programs, green procurement, and university-industry

partnerships can crowd in private R&D and build diffusion infrastructure, which fits the positive R&D association even if patents do not rise immediately. In developing economies, weaker intellectual property regimes, thinner university-industry linkages, and administrative frictions limit near-term conversion into patentable outputs and may crowd out private effort.

4.3. Mechanisms and heterogenous results

Placing the results within the induced innovation framework clarifies why price-based instruments perform differently across income groups. Taxes change relative prices and therefore the direction of technical change, favoring cleaner and efficiency-enhancing methods. Where innovation systems are mature and regulatory credibility is high, firms can reallocate R&D portfolios quickly, yielding productivity gains even without a rise in patents. The same tax in a weaker innovation ecosystem provides little inventive response because complementary capabilities are missing. Policy credibility matters as well. Transparent phase-ins, stable multi-year trajectories, and credible enforcement lower the value of waiting and encourage investment in cleaner processes. On the spending side, outcomes depend on composition. Programs that fund knowledge creation and diffusion, competitive grants, pilots, and shared infrastructure are more likely to complement private R&D.

5. Conclusion

This paper provides new empirical evidence on the differential effects of market-based environmental regulation on productivity and innovation, using an unbalanced panel of 48 countries, 30 developed and 18 developing, over the period 1995-2021. By distinguishing between environmental taxes and public environmental protection expenditures, and by adopting an instrumental variable approach to correct for endogeneity, the study contributes to a more nuanced understanding of the Porter Hypothesis across varying economic and institutional contexts.

Findings are heterogeneous. In developed countries, environmental taxes are positively associated with productivity, consistent with the idea that well-designed market-based instruments can stimulate efficiency-enhancing innovation. However, this effect is not observed in developing countries, suggesting that regulatory effectiveness is contingent upon governance capacity, policy credibility, and technological readiness. The relationship between environmental regulation and innovation is more nuanced. Both taxes and public expenditures are associated with lower patent activity, particularly in developing economies, yet taxes appear to stimulate R&D spending in advanced economies. This indicates that regulatory signals may trigger upstream innovation efforts, even if these do not immediately translate into formal innovation outputs such as patents. Furthermore, public environmental protection expenditures are associated with lower productivity across country groups, consistent with transition costs or inefficiencies. The IV results indicate that failing to address endogeneity, particularly around tax policy, can bias conventional fixed-effects estimates.

From a policy perspective, the results underscore three core messages:

1. Environmental taxes can be economically beneficial, but only when they are embedded in supportive institutional and innovation ecosystems. In contexts of weak enforcement or limited absorptive capacity, the same instruments may fail to deliver intended outcomes.

2. Instrument choice and policy design matter. The divergence between taxes and public expenditures suggests that green regulation is not monolithic. Rather, its effects depend on the incentives it creates, the sectors it targets, and the governance mechanisms that accompany its implementation.
3. For developing economies, scaling up the productivity and innovation benefits of green regulation will require complementary reforms: strengthening innovation systems, improving public financial management, and aligning environmental regulation with broader industrial and development strategies.

Several limitations of this study should be acknowledged. First, the measurement of environmental regulation remains imperfect due to inconsistencies in international reporting, especially in lower-income countries. Second, the use of aggregate macro-level data prevents us from capturing firm-level heterogeneity in responses to regulation, an area where future research could make significant contributions by leveraging microdata. Third, the binary classification of countries into "developed" and "developing" simplifies a continuum of institutional and economic realities. Middle-income countries, in particular, may face hybrid challenges that are not fully captured by this dichotomy.

Finally, further research is needed to explore the optimal design of green regulatory frameworks. Leveraging firm-level microdata, richer country and policy typologies, and improved regulatory measures can clarify which design features jointly advance environmental protection, technological change, and inclusive growth.

Appendix

Descriptive statistics

Table A1 – *Full sample*

Variable	Obs	Mean	Std. dev.	Min	Max
Labor	1343	15.746	1.624	11.894	20.479
Investment	1296	24.574	1.648	20.484	29.169
VA – Manufacturing sector	1278	24.148	1.722	19.765	28.795
R&D expenditures	1026	1.5	0.938	0.070	4.930
Patent applications	1174	7.892	2.202	1.386	14.277
Environmental tax	985	23.442	2.503	17.051	31.359
Public environmental protection expenditures	943	22.054	2.363	16.304	29.551
Education	1125	56.558	26.237	2.765	166.666
Inflation	1344	5.479	15.24	-9.899	415.81

Table A2 – *Developed countries*

Variable	Obs	Mean	Std. dev.	Min	Max
Labor	840	15.287	1.534	11.894	18.049
Investment	840	26.385	1.654	22.261	29.153
VA – Manufacturing sector	835	24.901	1.651	20.741	27.882
R&D expenditures	833	24.384	1.744	20.372	27.628
Patent applications	709	1.862	0.875	0.236	4.930
Environmental tax	768	7.826	2.314	1.386	12.993
Public environmental protection expenditures	700	23.296	2.614	17.051	31.359
Education	715	21.795	2.242	16.304	29.551
Inflation	708	65.629	21.728	7.484	166.666
Labor	840	2.601	3.247	-9.899	31.409

Table A3 – *Developing countries*

Variable	Obs	Mean	Std. dev.	Min	Max
Labor	503	16.513	1.475	13.136	20.479
Investment	504	25.757	1.691	22.291	30.423
VA – Manufacturing sector	461	23.983	1.469	20.484	29.169
R&D expenditures	445	23.707	1.59	19.765	28.795
Patent applications	317	0.691	0.435	0.070	2.433
Environmental tax	406	8.017	1.97	1.386	14.277
Public environmental protection expenditures	285	23.801	2.172	18.656	29.749
Education	228	22.867	2.549	16.765	29.538
Inflation	417	41.157	26.071	2.765	127.578
Labor	504	10.275	23.783	-5.992	415.81

List of countries in the sample (48 countries: 30 developed and 18 developing)

Developed Countries (30): Australia, Austria, Belgium, Canada, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Japan, South Korea, Netherlands, New Zealand, Latvia, Norway, Singapore, United Kingdom, Luxembourg, Spain, Italy, Portugal, Sweden, Slovenia, Slovak Republic, Switzerland, Malta.

Developing Countries (18): Argentina, Botswana, Brazil, Chile, China, Colombia, Côte d'Ivoire, Egypt, Georgia, Kenya, Senegal, Thailand, Tunisia, Turkey, South Africa, Poland, Ukraine, Malaysia.

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