

The Effect of Environmental Regulation Stringency on Productivity and Innovation: Testing the Porter Hypothesis

Chris Z. Kumala

Rangitoto College, 564 East Coast Road, Mairangi Bay, Auckland, 0630, New Zealand; Chriskumala88@outlook.com

Mentor: Dr. Ceyhun Elgin

ABSTRACT: Decisions made by the manufacturing industry are often presented as a tradeoff between efficiency and environmental responsibility. Contrary to this, Porter's Hypothesis (PH) argues that well-designed environmental regulation can stimulate innovation, possibly increasing productivity. We explore the relationship between the stringency of environmental regulation and short-term changes in productivity within the manufacturing sector. This paper hypothesizes that stringent environmental regulation leads to no increase in productivity in regulated manufacturing sectors; rather, inventive activity may increase, in line with the Weak PH. Using OECD productivity and EU patent data, combined with EU Emissions Trading System (ETS) emissions and allowance data across OECD countries, this study uses panel data at the country–industry level from 1998 to 2010. Baseline regressions employ a two-way fixed effects model with country–industry linear trends to estimate the association between lagged log regulatory stringency and productivity and innovation, alongside event studies around the ETS introduction. The results show that lagged log stringency is not statistically associated with short-run changes in productivity or innovation, with coefficients close to zero across periods. Overall, the findings show limited support for both the Weak and Strong PH in the short run and suggest policymakers should not expect instant gains following environmental regulation.

KEYWORDS: Economics, Environmental Economics, Climate Policy, Porter's Hypothesis, EU Emissions Trading System.

■ Introduction

The neoclassical view holds that stringent environmental regulation impedes innovation and thereby growth on the sector level. Proponents of stringent environmental regulation counter this view, arguing that increasing the stringency of environmental regulation provides just cause for firms to innovate in order to reduce new compliance costs. Under this assumption, sector-wide productivity increases while environmental spillover costs decrease. This process is based on Schumpeter's idea of Creative Destruction¹, whereby new processes make old processes obsolete, resulting in more productive technologies. Consistent with endogenous growth frameworks such as Romer², regulatory pressure may therefore affect short-run productivity through induced technological change. Porter and van der Linde formalized this mechanism³ with their theory, coining Porter's Hypothesis. Specifically, they argued that markets with asymmetric information, organizational inertia, and control problems create market imperfections. When environmental regulation is introduced, firms are pushed to react by exploring overlooked paths for technological improvement.

Further literature has created two distinct ways the PH can act at the firm level. Jaffe *et al.* are commonly credited⁴ with articulating the “Weak” and “Strong” PH. First, the “Weak” PH claims that well-designed environmental regulation induces innovation accompanied by a limited or unclear impact on sector-level productivity. Second, the “Strong” PH postulates that well-designed regulation leads to innovation in technologies that improve a firm's productivity, thereby causing a net positive effect on sector-level productivity. While the “Weak” PH is widely accepted as true within the medium and

long-term, recent scholarship has suggested that the effects of environmental regulation differ substantially across sectors, policy instruments, and time periods. Dechezleprêtre and Sato⁵ supported the notion that environmental regulation can stimulate green innovation. Yet, increases in competitiveness and productivity are subject to policy design and adjustment periods. Similarly, Ambec *et al.*⁶ suggested that regulation must be sufficiently stringent for the Porter-style effects to occur. Therefore, the regulation design is a likely factor in determining whether innovation offsets compliance costs in the short run. Whether the “Strong” PH is backed by empirical data is more heavily contested.

This paper assesses whether stringent environmental regulation leads to short-term productivity gains in the manufacturing sector. This question has particular importance even beyond environmental economics, as governments increasingly adopt environmental regulation; understanding the effects of such policy is important for policymakers, so informed decisions can be made. Addressing it requires engaging with empirical literature that tests Porter's Hypothesis and evaluates whether innovation caused by stringent environmental regulation translates into concrete productivity gains. Nonetheless, Porter's initial hypothesis was rather constrained as it was primarily anecdotal and based on limited empirical evidence. Hence, contemporary scholarship has sought to use data to reveal the true relationship between the stringency of environmental regulation and productivity gains. These studies have been largely focused on the United States and other OECD economies, with emphasis on the medium to long-term effects on energy-intensive manufacturing sectors.

However, recent papers have reached heterogeneous conclusions. Earlier studies, particularly those focusing on the United States, found that compliance costs associated with pollution abatement imposed net costs on firms, with limited evidence of productivity-enhancing innovation. Gray and Shadbegian⁷ examined firm-level data from US manufacturing industries, concluding that expenditure went towards directly covering the cost of the regulation rather than innovation. Contrary to this conclusion, more recent work has supported that the “Weak” PH holds within the medium and long run. Rubashkina, Galeotti, and Verdolini present empirical evidence⁸ from the European manufacturing sectors to show that pollution abatement and Control Expenditures induce innovation proxied by patent counts, consequently supporting the Weak PH. Albrizio, Kozluk, and Zipperer use OECD Environmental Policy Stringency data⁹ and firm-level panel data to find that productivity gains often lag instead of occurring immediately. Within the EU ETS specifically, Martin, Muûls, de Preux, and Wagner¹⁰ found limited evidence supporting significant productivity losses among regulated firms, with innovation effects remaining uneven. Cael and Dechezleprêtre¹¹ show that EU ETS exposure increased low-carbon patenting among regulated firms, supporting the weak PH over the long run. However, Abrell, Ndoye Faye, and Zachmann¹² argue that overallocation and low allowance prices significantly weakened compliance incentives, possibly limiting both productivity and inventive activity in the short run. Consequently, null effects may reflect weak policy implementation rather than a failure of Porter Hypothesis mechanisms. Thus, despite substantial scholarship on medium and long-run innovation effects, evidence on short-run responses to stringent environmental regulation is limited and mixed, especially during implementation that entails more immediate adjustment costs and compliance pressure.

This paper hypothesizes that stringent environmental regulation leads to no increase in productivity in regulated manufacturing sectors; rather, inventive activity increases, in line with the Weak Porter Hypothesis. The following discourse shall address the following. Section 2 will discuss the method and data used. Section 3 will provide the main results, while Section 4 will explore them in context. Section 5 will conclude.

■ Data

Data sources:

To examine the short-term effects of stringent environmental regulation on productivity within the European manufacturing sector, our study relied on a relatively large cross-country dataset constructed from the OECD Structural Analysis (STAN) database¹³ and the EU Emissions Trading System (ETS) data viewer.¹⁴ In addition to productivity outcomes, the effects on innovation activity were measured using the Eurostat Patent Application database.¹⁵ To facilitate event studies or both the baseline productivity and innovation regressions, pre-2005 emissions data from the OECD Air Emissions Accounts Database¹⁶ were used. The OECD STAN database is a tool for analyzing economic performance at the industry level, providing annual measures such as out-

put, value added, and capital stock. In this paper, it was used to derive the country-year-industry panel of manufacturing activity, including metrics for Value added, Total Employment, and Labor productivity. The STAN sample used involves manufacturing industries from 23 EU countries observed annually over the period (1998-2010). These industries will be referred to by their International Standard Industry Classification (ISIC) Rev. 4 classification codes. Particular attention is paid to energy-intensive manufacturing industries, including Manufacture of paper and paper products (C17), Manufacture of coke and refined petroleum products (C19), Manufacture of other non-metallic mineral products (C23), and Manufacture of basic metals (C24). These manufacturing industries are among the most emissions-intensive and therefore plausibly have high ETS exposure, targeted by the introduction of the EU ETS in 2005. Now, with regard to the EU ETS, its introduction in 2005 represents a major tightening in environmental regulatory stringency. Specifically, a cap-and-trade system was introduced, requiring regulated industries to have allowances equal to their emissions. The sample extracted from the data viewer used verified emissions and allocated allowances for 23 EU countries at the Country-Year level, covering the period 2005-2010, corresponding to the early years of the ETS. The Eurostat Patent application database provided country-industry-year level data on the number of patent applications submitted each year. In this paper, data was used to derive data to proxy for innovation activity. The sample we extracted covered 1998-2010, spanning the same 23 EU countries and 4 manufacturing sectors as the STAN sample. We used the OECD Air Emissions Accounts database to provide pre-2005 emissions data, which was not available in the ETS database. Our sample contained country-industry-year level data for the 23 EU countries. The OECD STAN and EU ETS datasets were merged at the country-year level to create a final sample with stringency and productivity data. To ensure observations were subject to the same regulatory framework, OECD countries that were not present in the EU ETS data were excluded. In addition, some country-industry-year observations were dropped in cases where employment was reported as zero or value added as negative, thereby preventing the calculation of labor productivity. These restrictions mean that the analysis is based on economically meaningful data. Eurostat patent application data were also merged with EU ETS data at the country-year level to create a dataset with both patent and emissions data. The baseline productivity and innovation regressions are limited to 2005-2010 since the lagged EU ETS stringency proxy requires both verified emissions and allowance data, which are only reliably available post-2005. This results in 383 usable productivity observations and 375 usable innovation observations after exclusions. The event studies use a wider 1998-2010 panel and rely on pre-policy emissions exposure, with the productivity event study having 987 observations and the innovation event study having 975 observations.

Variable Construction:

The key independent variable was environmental regulation stringency. Direct sector-country-year measures of environmental regulatory stringency are particularly limited, especially within the EU ETS framework. Thus, effective environmental regulation stringency has been proxied with the ratio of verified emissions to allocated allowances under the EU ETS. Stringency is first constructed as the emissions-to-allowances ratio lagged by one year, then log-transformed for the regression. The measure used captures the effective bindingness of emissions regulation, since sectors with verified emissions that are close to or exceeding allocated allowances face greater compliance pressure, and thereby stronger incentives to improve efficiency.

$$\text{LogStringency}_{ict,t-1} = \log\left(\frac{\text{VerifiedEmissions}_{ict,t-1}}{\text{AllocatedAllowances}_{ict,t-1}}\right)$$

While the proxy used reflects the realized compliance pressure instead of legislative strictness, it more clearly captures regulatory burden within the EU ETS framework than wider environmental policy datasets such as the OECD Environmental Policy Stringency (EPS) Index.¹⁷ OECD EPS measures national-level policy settings, but lacks the sector-country-year granularity and does not reflect sector-specific compliance pressure faced by regulated industries. By using the ratio of verified emissions to allocated allowances, the degree to which regulated sectors approach exceeding emissions caps is directly reflected, therefore serving as a more precise indicator of compliance pressure under cap-and-trade regulation. That said, it may partially reflect differences in firm efficiency or emissions intensity. As such, alternative measures such as carbon pricing indicators and wider environmental policy stringency indices were considered, but were not used as they lacked sufficient industry-country-year granularity for this analysis. To mitigate simultaneity concerns, the variable is logged and lagged by one year, though this does not fully eliminate possible endogeneity. Results should be interpreted as better reflecting effective regulatory pressure rather than pure legislative stringency. To assess the sensitivity of findings to variable construction and reduce concerns regarding possible outlier distortion, robustness checks were performed using a winsorized variation of the stringency ratio as an alternative specification of environmental regulation stringency.

The dependent variable used to test productivity in this study was labor productivity, measured as the logarithm of value added per worker. This is widely used in Porter Hypothesis literature as an indicator of efficiency. Specifically, productivity is constructed using value added (VA) and total employment from the OECD STAN database as

$$\text{Productivity}_{ict} = \log(\text{VA}_{ict}) - \log(\text{employment}_{ict})$$

By using logarithms, can reduce the skewness in the data while also making productivity levels comparable across heterogeneous units.

To proxy innovation, we used patent applications as a measure of inventive activity and technological change. This allows for a broad and observable proxy for new inventive output, though it is unable to capture factors such as innovation qual-

ity or non-patented innovation. The specific construction of the proxy is below.

$$\text{Innovation}_{ict} = \log(\text{Patent Applications}_{ict} + 1)$$

By adding +1, we avoided any invalid results from log(0).

Country-industry fixed effects control for time-invariant structural differences across sectors, and year fixed effects capture common macroeconomic shocks over time.

Summary Statistics:

Table 1: Summary statistics for productivity regression. The statistics indicate substantial variation in productivity across countries and industries. The negative mean value of lagged log stringency suggests that emissions were generally below allocated allowances during the sample period.

Summary Statistics: Productivity Regression Sample					
	Mean	SD	Min	Max	N
productivity	4.86	1.86	-1.63	11.84	383
log_stringency_lag1	-0.19	0.18	-0.96	0.27	383
log_employment	2.58	1.77	-5.81	5.64	383

Table 1 reports the summary statistics for the main variables used in the empirical analysis. Labor productivity has a mean of 4.86 (SD = 1.86), indicating substantial variation across countries, industries, and time. Lagged log stringency, defined as the log of verified emissions divided by allocated allowances (t-1), had a mean of -0.19 (SD = 0.18), indicating that emissions were often below allocated allowances. This suggests that in the early ETS period, many industries faced relatively weak compliance pressure.

Log employment has a mean of 2.58 (SD = 1.77), suggesting heterogeneity in industry size. The sample consists of 383 observations over the period of 2005-2010.

Table 2: Summary statistics for innovation regression. Patenting activity varies considerably across observations. The relatively low average stringency value suggests that many industries faced limited compliance pressure during the early ETS period.

Summary Statistics: Innovation Regression Sample					
	Mean	SD	Min	Max	N
log_patents	1.82	1.54	0.00	5.97	375
log_stringency_lag1	-0.19	0.18	-0.96	0.27	375

Table 2 shows the summary statistics for the variables used in the innovation regression. The mean value of log patents is 1.82 (SD = 1.54), indicating substantial variation in patent activity. Lagged log stringency had a mean of -0.19 (SD = 0.18), indicating that emissions were often below allocated allowances. The sample consists of 375 observations over the period of 2005-2010. The smaller sample size relative to the productivity regressions was caused by missing patent observations in some country-industry-year groups.

Empirical Strategy

Baseline Two-Way Fixed Effects Specification:

To estimate the short-run relationship between stricter environmental regulation and productivity within the manufacturing sector, this paper employs a panel fixed effects style framework with two-way fixed effects and country-industry linear time trends.

$$Productivity_{ict} = \beta \log(stringency_{c,t-1}) + \gamma \log(employment_{ict}) + \alpha_{ic} + \lambda_t + \delta_{ic} t + \varepsilon_{ict}$$

Where $Productivity_{ict}$ represents the labor productivity in industry i , country c , and year. $\log(stringency_{c,t-1})$ denotes lagged log stringency, measured as the logarithm of verified emissions divided by allocated allowances. $employment_{ict}$ controls for employment. Industry-country fixed effects (α_{ic}) absorb differences in technology, structure, and productivity levels across country-industry pairs that do not change over time. Year fixed effects (λ_t) absorb macro shocks that affect all manufacturing sectors and countries. Country-industry specific linear time trends ($\delta_{ic}t$) account for differential pretrends across country-industry pairs. Lastly, the error term (ε_{ict}) accounts for unobserved factors affecting productivity that vary across country, industry, and time. Identification comes from within-country-industry variation over time. The final panel includes 58 country-industry units observed across 3 post-treatment years.

Identification and Interpretation:

The two-way fixed effects used in the model help to isolate the effect of increasing the $\log(stringency_{c,t-1})$ of environmental regulation by removing confounding factors that are constant over time within country-industry pairs. The coefficient of interest in this case is β , as it captures the short-run response of productivity to the EU ETS Scheme.

The approach used in this study provides quasi-causal experimental evidence under standard panel data assumptions, although results should be interpreted as short-run associations instead of purely causal effects. Accordingly, the results provide insight into short-run industry-level adjustment and compliance responses to the 2005 EU ETS regulation, rather than long-run innovation-driven impacts.

Event Study design:

To improve the credibility of the empirical model, the initial analysis for both productivity and innovation was complemented with an event study, focusing on the introduction of the EU ETS in 2005. In particular, the event study tests the parallel trends assumption and provides insight into the dynamics of productivity before and after 2005. The specification is given by

$$Productivity_{ict} = \sum_{k \neq -1} \beta_k (average\ emissions_{1998-2004}^{x1[event_time = k]}) + \alpha_{ic} + \lambda_t + \delta_{ic} t + \varepsilon_{ict}$$

Where $event_time = t-2005$ indexes year relative to the introduction of the EU ETS. $event_time = k$ is a dummy variable that equals one if year t is k years away from 2005. ETS exposure captures time-invariant differences in regulatory exposure, measured using average emissions intensity in the pre-policy period (1998–2004). The pre-treatment year ($k-1$) is removed from the regression as it acts as the baseline.

A separate coefficient β_k is estimated for each year relative to the introduction of the ETS. The coefficients for pre 2005 years test for differential trends before the policy shock.

Innovation empirical strategy:

A second two-way fixed effects baseline model was estimated to examine whether the EU ETS induced innovative

activity in the short run. To do this, the baseline specification was re-estimated with innovation as the dependent variable:

$$Innovation_{ict} = \beta \log Stringency_{c,t-1} + \alpha_{ic} + \lambda_t + \delta_{ic} t + \varepsilon_{ict}$$

Where $innovation_{ict}$ represents the level of innovation in industry i , country c , and year. As in the productivity model, $\log(stringency_{c,t-1})$ is the measure of environmental regulation stringency, proxied by lagged log regulatory stringency. Furthermore, industry-country, year, and country-industry fixed effects are used in the same manner as the productivity baseline regression. The error term accounts for unobserved factors.

To assess the Weak Porter Hypothesis, the same event study framework was applied using innovation as the dependent variable.

$$Innovation_{ict} = \sum_k \beta_k (average\ emissions_{1998-2004}^{x1[event = k]}) + \alpha_{ic} + \lambda_t + \delta_{ic} t + \varepsilon_{ict}$$

This innovation event study examines whether more highly exposed manufacturing sectors had pre-trends in inventive activity before the introduction of ETS in 2005.

Limitations:

The chosen data and methodology used have a couple of important limitations. The use of country-industry and year fixed effects improves validity by controlling for unobserved heterogeneity, but combined with the relatively limited sample size (382 observations), may reduce statistical precision. Therefore, standard errors may be higher, limiting the study's ability to detect smaller short-run effects. In addition, the proxy used reflects realized compliance pressure, instead of legislative strictness. While it is practical, given data constraints, this measure may also partially capture differences in efficiency. Similarly, patent applications offer an observable measure of inventive activity, but may not fully capture innovation quality, process improvements, or non-patented technological adaptations. Moreover, because this study focuses on short-run effects within EU ETS-regulated sectors, findings may not generalize to long-run outcomes or non-European policy environments.

Results

Our baseline model estimated the association between labor productivity and environmental regulation stringency, proxied by lagged log stringency.

In Table 3, we report the results from the baseline and robustness regression using a two-way fixed effects specification with country-industry fixed effects. Column (1) reports the baseline estimate where the coefficient on lagged regulatory stringency is 0.005 (SE = 0.187), indicating no short-run relationship between lagged log stringency and labor productivity. In Column (2), adding country-industry linear trends increases the coefficient to 0.011 (SE = 0.306), but it remains statistically insignificant. Columns (3) and (4) test robustness by restricting the time period to phase 1 of ETS (2005–2007) and excluding the crisis years 2008–2009. The estimated effects (0.052 and 0.025, respectively) remain statistically insignificant. Across all specifications, Log employment is negative and statistically significant, which reveals that within a country-industry, years with more workers are associated with lower productivity. This is consistent with diminishing returns. Overall, the baseline re-

sults suggest that stricter environmental regulation does not result in short-run productivity gains.

Table 3: Two-way fixed effects regressions of labor productivity. Across all specifications, the estimated effect of regulatory stringency remains small and statistically insignificant. These results provide little evidence that stricter environmental regulation increased short-run productivity.

Productivity: Baseline and Robustness Checks				
	Baseline	+ IC trends	Phase I (05–07)	Drop 08–09
log_stringency_lag1	0.005 (0.204)	0.011 (0.306)	0.052 (0.331)	0.025 (0.147)
log_employment	-1.016*** (0.174)	-0.745*** (0.084)	-3.497* (1.591)	-1.253* (0.506)
Num.Obs.	383	383	154	229
R2	0.972	0.984	0.985	0.977
R2 Adj.	0.965	0.973	0.969	0.965
R2 Within	0.167	0.092	0.308	0.195
R2 Within Adj.	0.161	0.084	0.289	0.184
AIC	353.7	297.0	154.6	232.1
BIC	681.4	928.7	397.6	510.2
RMSE	0.31	0.23	0.24	0.28
Std.Errors	by: ref_area	by: ref_area	by: ref_area	by: ref_area
FE: ref_area^activity	X	X	X	X
FE: year	X	X	X	X
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001				
Country-industry fixed effects: 58				
Year fixed effects: 3 years				
Standard errors clustered at the country-industry level (58 clusters)				

Each column contains estimates from regressions with country-industry and year fixed effects. Standard errors (SE) are clustered at the country level and reported in parentheses.

Graphical evidence:

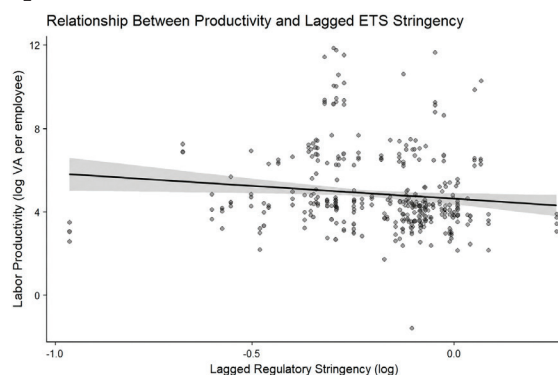


Figure 1: Productivity vs lagged regulatory stringency. The fitted relationship is slightly negative and weak. This suggests that cross-sectional differences in regulatory stringency alone do not strongly predict productivity outcomes.

Figure 1 plots labor productivity against lagged regulatory stringency and creates a slightly negative fitted relationship. Furthermore, the scatter plot revealed substantial dispersion at similar emission levels, suggesting that the cross-sectional variation alone did not tightly predict productivity when comparing different country-industry pairs.

Figure 2 shows lagged regulatory stringency over the period 2006–2010. Emissions followed a modest upward trend initially before sharply declining around 2008–2009, coinciding with both the tightening of ETS rules and the global financial crisis. This graph highlights the meaningful changes in

emissions intensity. However, this paper focuses largely on the short-term effects, reflecting the period 2005–2006.

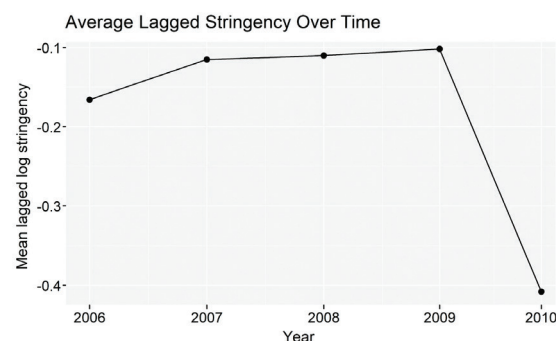


Figure 2: Average ETS emissions over time (2005–2010). Average ETS emissions increased slightly before declining sharply after 2008. This indicates a substantial change in emissions levels during the latter part of the sample period.

Even so, fixed effects absorb common macroeconomic shocks.

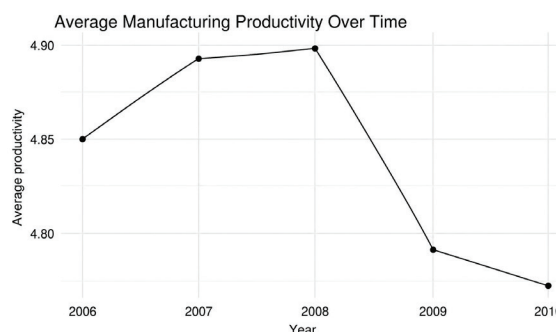


Figure 3: Average manufacturing productivity over time (2005–2010). Productivity increased slightly between 2006 and 2008 before declining noticeably after 2008. Overall, there is no clear evidence of sustained productivity growth following the introduction of the EU ETS.

Event-study Evidence:

To examine whether productivity trends differed by ETS exposure before the policy shock and to examine short-run dynamics after the start of the ETS, an event-study specification was run using panel data from 1998 to 2010.

Table 4 reports the full set of event-time coefficients from this specification, including standard errors clustered at the country level and controlling for country-industry and year fixed effects. Across event times -7 to -2, all coefficients were close to zero and thereby statistically insignificant. This means that there is no evidence of differential pre-trends in productivity across ETS-exposed industries before 2005. Furthermore, around the policy implementation and in subsequent years, the coefficients remain close to zero, suggesting that higher-pre ETS exposure is not associated with significant short-run changes in productivity following the introduction of ETS. In short, the event study supports the baseline findings, showing no significant changes to short-run productivity after the introduction of ETS.

Table 4: Event-Study regression results. Both pre-treatment and post-treatment coefficients remain close to zero and statistically insignificant. This suggests no detectable short-run productivity response to ETS exposure.

Event Study Results: Productivity and Pre-ETS Exposure	
Event study (Productivity)	
event_time = -7 × Exposure_ic	2.3e-06 (1.8e-06)
event_time = -6 × Exposure_ic	2.5e-06 (1.9e-06)
event_time = -5 × Exposure_ic	2.5e-06 (1.4e-06)
event_time = -4 × Exposure_ic	2.2e-06 (1.2e-06)
event_time = -3 × Exposure_ic	1.6e-06 (1.2e-06)
event_time = -2 × Exposure_ic	8.7e-07 (1.0e-06)
event_time = 0 × Exposure_ic	-2.1e-07 (1.0e-06)
event_time = 1 × Exposure_ic	6.1e-07 (1.3e-06)
event_time = 2 × Exposure_ic	-7.8e-07 (1.2e-06)
event_time = 3 × Exposure_ic	-1.8e-06 (1.3e-06)
event_time = 4 × Exposure_ic	-1.7e-06 (1.1e-06)
event_time = 5 × Exposure_ic	-1.8e-06 (1.3e-06)
Num. Obs.	987
R2	0.959
R2 Within	0.044
Std. Errors	Clustered by: ref_area
FE: REF_AREA^ACTIVITY	Yes
FE: YEAR	Yes
Country-industry fixed effects: 58	
Year fixed effects: 3	
Standard errors clustered at the country-industry level (58 clusters)	

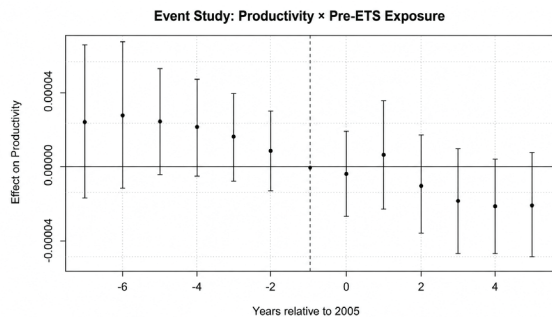


Figure 4: Event study plot. The estimated coefficients fluctuate around zero, and their confidence intervals generally include zero. This provides visual support for the absence of significant productivity effects following ETS implementation.

Figure 4 plots the estimated event-study coefficients consistent with Table 4.

Innovation results:

Table 5 reports the baseline and robustness estimates of the relationship between lagged log stringency and innovation, proxied by log patents. The coefficient on lagged log stringency was 0.045 with a SE 0.170) and statistically insignificant, which implies that there was no short-term increase in innovation activity. By adding country-industry linear trends in Column (2), we found a negative but imprecise coefficient of -0.325 (SE = 0.173), and restricting estimates to 2005–2007 provided a similar estimate of -0.233. All coefficients are statistically

insignificant and indistinguishable from zero, suggesting that increased lagged log stringency did not lead to any meaningful increase in short-run patenting.

Table 5: Innovation baseline regression results. The estimated effects of regulatory stringency on patenting are statistically insignificant across all specifications. These findings provide limited support for the Weak Porter Hypothesis in the short run.

Innovation: Baseline and Robustness Checks				
	Baseline	+ IC trends	Phase I (05–07)	Drop 08–09
log_stringency_lag1	0.045 (0.170)	-0.325+ (0.173)	-0.233 (0.318)	0.217 (0.241)
Num.Obs.	375	375	150	225
R2	0.967	0.981	0.983	0.969
R2 Adj.	0.959	0.967	0.965	0.953
R2 Within	0.000	0.012	0.003	0.008
R2 Within Adj.	-0.003	0.007	-0.010	0.001
AIC	261.3	217.3	97.8	202.5
BIC	575.5	826.0	329.6	468.9
RMSE	0.28	0.21	0.20	0.27
Std.Errors	by: ref_area	by: ref_area	by: ref_area	by: ref_area
FE: ref_area^activity	X	X	X	X
FE: year	X	X	X	X
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001				
Country-industry fixed effects: 58				
Year fixed effects: 3 years				
Standard errors clustered at the country-industry level (58 clusters)				

Table 6: Innovation event study regression results. Pre-policy coefficients show no evidence of differential trends, while post-policy coefficients remain close to zero. This suggests that ETS exposure did not generate measurable short-run increases in patenting activity.

Event Study Results: Innovation and Pre-ETS Exposure	
Event study (Innovation)	
event_time = -7 × Exposure_ic	-1.1e-06 (1.2e-06)
event_time = -6 × Exposure_ic	9.5e-07 (1.0e-06)
event_time = -5 × Exposure_ic	2.2e-07 (1.1e-06)
event_time = -4 × Exposure_ic	8.3e-07 (1.0e-06)
event_time = -3 × Exposure_ic	5.4e-07 (1.0e-06)
event_time = -2 × Exposure_ic	1.2e-06 (1.0e-06)
event_time = 0 × Exposure_ic	9.9e-07 (1.0e-06)
event_time = 1 × Exposure_ic	1.3e-06 (1.0e-06)
event_time = 2 × Exposure_ic	9.1e-07 (1.0e-06)
event_time = 3 × Exposure_ic	7.1e-07 (1.1e-06)
event_time = 4 × Exposure_ic	5.5e-07 (1.1e-06)
event_time = 5 × Exposure_ic	7.1e-07 (1.2e-06)
Num. Obs.	975
R2	0.961
R2 Within	0.011
Std. Errors	Clustered by: ref_area
FE: REF_AREA^ACTIVITY	Yes
FE: YEAR	Yes
Country-industry fixed effects: 58	
Year fixed effects: 3	
Standard errors clustered at the country-industry level (58 clusters)	

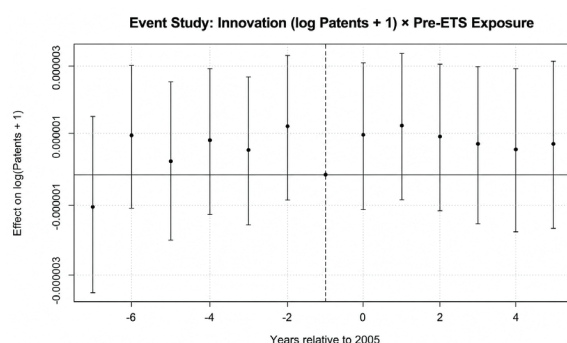


Figure 5: Innovation event study regression plot. The estimated effects remain small and statistically insignificant throughout the study period. This visual evidence is consistent with the baseline innovation regressions.

In order to confirm our conclusion, we ran an event study to examine pre-trends. Table 6 and Figure 5 present the results. The coefficients in the pre-policy period (event times -7 to -2) were small in magnitude and statistically insignificant, thereby providing no evidence of differential pre-trends. Following the introduction of ETS, coefficients remain close to zero and statistically insignificant across all post-policy event times. Overall, the results are consistent with, but do not prove, the parallel trends assumption, thereby supporting the baseline regression results. These results provide very limited evidence in support of the Weak Porter's hypothesis within the short run, as innovative activity did not experience a meaningful increase.

Robustness Checks:

To assess the stability of the baseline findings, a lagged winsorized logged specification of environmental regulation stringency was used, while retaining the same fixed-effects and standard-error framework. The construction of the variable can be seen below:

$$\text{WinsorisedLogStringency}_{ic,t-1} = \text{lag}\left(\text{Winsorise}\left(\log\left(\frac{\text{VerifiedEmissions}_{ic,t-1}}{\text{AllocatedAllowances}_{ic,t-1}}\right)\right)\right)$$

As shown in Table 7, the coefficient on lagged winsorized log stringency was negative for productivity (-0.019) and positive for innovation (0.046), yet both remained statistically insignificant. Therefore, the winsorized logged specification produced results that were consistent with the baseline regressions. This suggests that the baseline findings are robust to alternative treatment of extreme observations and are not disproportionately driven by outlier values.

Table 7: Winsorized robustness check results. The coefficients remain statistically insignificant after reducing the influence of extreme observations. This suggests that the baseline findings are not driven by outliers.

Robustness Check: Winsorized Logged Environmental Stringency		
	Productivity Robustness	Innovation Robustness
Lagged Winsorized Log Stringency	-0.019	0.046
	(0.015)	(0.043)
Observations	383	383
R ²	0.996	0.984
Adjusted R ²	0.996	0.981
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001		
Country-industry fixed effects: 58		
Year fixed effects: 3 years		
Standard errors clustered at the country-industry level (58 clusters)		

In addition to this, to assess whether null findings were driven by limited statistical power, simplified model specifications were run with fewer controls. Only country-industry and year fixed effects were run with clustered SEs.

Table 8: Simplified model specification results. The simplified specifications produce estimates similar to the main models. This reinforces the conclusion that regulatory stringency had no detectable short-run effect on productivity or innovation.

Robustness Check: Simplified Model Specification		
	Productivity Simplified	Innovation Simplified
Lagged Logged Stringency	-0.004	0.008
	(0.003)	(0.010)
Observations	383	383
R ²	0.996	0.984
Adjusted R ²	0.996	0.980
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001		
Country-industry fixed effects: 58		
Year fixed effects: 3 years		
Standard errors clustered at the country-industry level (58 clusters)		

As observed in Table 8, the coefficient on productivity was -0.004, and the coefficient on innovation was 0.008, with both again being statistically insignificant. This supports the baseline null findings.

Discussion

The primary goal of this paper was to explore the relationship between environmental regulation stringency and productivity within the short run. We hypothesized that more stringent regulation would not immediately lead to increases in productivity; rather, inventive activity would experience an increase. Our study combined panel data from 22 OECD countries to show that, within the short run, more stringent regulation was not statistically associated with either increased productivity or innovation. Accordingly, the results do not support either the Strong or Weak Porter's Hypothesis in the short run. The baseline productivity regression results provided no evidence that lagged log stringency had a statistically significant effect on productivity once employment was controlled for. With regard to the event study, the pre-policy coefficients are close to zero and statistically insignificant, providing little evidence of differential pretrends. This strengthens the credibility of the empirical design and supports the interpretation of the baseline results as short-run associations. This finding is consistent with previous literature that suggests compliance pressure is often major, coupled with limited efficiency gains. Notably, Greenstone showed that manufacturing activity often decreases immediately after a policy shock, consistent with short-run adjustment costs. Overall, the absence of short-run productivity gains was expected and matched the consensus of previous research regarding the strong PH. To determine whether the absence of productivity gains reflects the time required for new technologies to materialize or if, instead, firms were focused on cost abatement, this paper also examined patent applications as a proxy for innovation. Our baseline regression showed no significant increase in inventive activity following the introduction of ETS. The innovation event study similarly supported the parallel trends assumption, as coefficients were practically indistinguishable from zero, in-

dicating no evidence of differential pre-trends. This suggests that the identifying assumptions are reasonably satisfied, although our estimates should still be interpreted as short-run associations rather than causal effects. While limited productivity gains were expected, the lack of an increase in inventive activity was surprising. One plausible explanation is that Phase 1 of the EU ETS may have generated insufficient compliance pressure as a result of generous allowance allocations, thereby weakening the incentives for immediate innovation. This interpretation is in line with Abrell *et al.*¹⁹ and explains the divergence between our short-run null findings and Cael & Dechezleprêtre's medium-run findings. As such, our results contrast with some other studies that test for innovation. One such paper, Cael and Dechezleprêtre, observed an increase in low-carbon patenting,⁹ among firms exposed to ETS over the medium run, supporting the Weak PH. The results suggest that even if regulation encourages firms to innovate, inventive activity may not occur immediately, with possible productivity gains emerging even later. Based on previous research focusing on the medium and long run, Innovation frequently takes time to translate into output efficiency due to adjustment costs. Our study has relevant implications for the field. Literature in this field tends to focus heavily on the medium and long run, leaving holes in understanding within the short-run. Importantly, this paper helps to bridge the gap in the literature by revealing that any productivity increases in line with the Strong PH do not occur within the short run. Literature in this field tends to agree that the Weak Porter's hypothesis, wherein Innovation increases in response to regulation, is valid. Yet, we found that more stringent regulation has little impact on inventive activity proxied by patents. Therefore, we can reasonably assume that inventive activity did not increase right after the introduction of ETS. By explicitly focusing on the short-run productivity and innovation effects, the results suggest that gains are not automatic. This has important implications for policy-makers, as our results suggest that expecting quick productivity gains is unreasonable. Instead, environmental policies may take longer to become effective. Policymakers should also avoid assuming that the effects of environmental regulation are homogeneous and will surely generate innovation or productivity gains in the short-run. Our results suggest that policymakers should look to make long-term policy commitments and sufficiently binding compliance in order to see a significant increase in technological improvements within industry. However, some limitations limit the interpretation of our results. First, while both event study estimates show little evidence of significant pre-trends, the relatively short time window constrains causal interpretation. Therefore, estimates should be interpreted cautiously as short-run associations rather than definitive causal effects. Second, patent applications might not fully capture changes in inventive activity. Future work in this field could explore the heterogeneity of policies and their effect, examine short-run effects from a firm-level perspective, or focus on technology spillovers. Lastly, given the relatively limited post-treatment sample and the extensive fixed-effects structure, statistical power may be constrained, so null findings should be interpreted

ed cautiously. In all, neither the Weak nor the Strong Porter's Hypothesis holds in the short run.

■ Conclusion

In conclusion, this paper finds no evidence in support of either the Strong or Weak Porter's Hypothesis within the short run. Our estimations find that increased lagged log stringency is not statistically associated with higher productivity or innovation over the 2005–2007 period. Furthermore, the event studies show little evidence of differential pre-trends, thereby supporting the parallel trends assumption. However, it is worth noting that the short time window limits causal interpretation. As such, all our estimates should be viewed as descriptive short-run associations, rather than clear causal effects. These findings challenge the assumption introduced at the beginning of this paper that environmental regulation necessarily creates innovation and further benefits as a result. Instead, firms facing such constraints likely prioritize cost-adjustment, which delays the realization of the Porter-style gains. With regard to policy implications, our evidence suggests that immediate productivity or innovation gains should not be expected shortly following the introduction of environmental regulation. Moreover, in the short run, such regulation may be insufficient to rapidly stimulate innovation unless paired with measures such as transitional subsidies. Future research should therefore focus on the regulatory conditions under which Porter-style gains may arise in the short run.

■ Acknowledgments

I want to express gratitude to my mentor, Dr. Ceyhun Elgin from Columbia University, for his guidance and detailed feedback during the research process. I also want to thank Daryn Howland for her support.

■ References

1. Schumpeter, J. A. *Capitalism, Socialism and Democracy*; Harper & Brothers: New York, 1942.
2. Romer, P. M. Endogenous Technological Change. *J. Polit. Econ.* **1990**, *98* (5), S71–S102.
3. Porter, M. E.; van der Linde, C. Toward a New Conception of the Environment–Competitiveness Relationship. *J. Econ. Perspect.* **1995**, *9* (4), 97–118. <https://doi.org/10.1257/jep.9.4.97>.
4. Jaffe, A. B.; Newell, R. G.; Stavins, R. N. Technological Change and the Environment. In *Handbook of Environmental Economics*; Mäler, K.-G., Vincent, J. R., Eds.; Elsevier: Amsterdam, 2003; Vol. 1; pp 461–516.
5. Gray, W. B.; Shadbegian, R. J. Plant Vintage, Technology, and Environmental Regulation. *J. Environ. Econ. Manage.* **2003**, *46* (3), 384–402. [https://doi.org/10.1016/S0095-0696\(03\)00031-7](https://doi.org/10.1016/S0095-0696(03)00031-7).
6. Rubashkina, Y.; Galeotti, M.; Verdolini, E. Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors. *Energy Policy* **2015**, *83*, 288–300. <https://doi.org/10.1016/j.enpol.2015.02.014>.
7. Albriizio, S.; Kozluk, T.; Zipperer, V. Environmental Policies and Productivity Growth: Evidence across Industries and Firms. *J. Environ. Econ. Manage.* **2017**, *81*, 209–226. <https://doi.org/10.1016/j.jeem.2016.06.002>.

8. Martin, R.; Muûls, M.; de Preux, L. B.; Wagner, U. J. Industry Compensation under Relocation Risk: A Firm-Level Analysis of the EU Emissions Trading Scheme. *Am. Econ. Rev.* **2014**, *104* (8), 2482–2508. <https://doi.org/10.1257/aer.104.8.2482>.
9. Cabel, R.; Dechezleprêtre, A. Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market. *Rev. Econ. Stat.* **2016**, *98* (1), 173–191. https://doi.org/10.1162/REST_a_00470.
10. Abrell, J.; Ndoye Faye, A.; Zachmann, G. Assessing the Impact of the EU ETS Using Firm-Level Data; Bruegel Working Paper No. 2011/08; Bruegel: Brussels, 2011.
11. Dechezleprêtre, A.; Sato, M. The Impacts of Environmental Regulations on Competitiveness. *Rev. Environ. Econ. Policy* **2017**, *11* (2), 183–206. <https://doi.org/10.1093/reep/rex013>.
12. Ambec, S.; Cohen, M. A.; Elgie, S.; Lanoie, P. The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? *Rev. Environ. Econ. Policy* **2013**, *7* (1), 2–22. <https://doi.org/10.1093/reep/res016>.
13. Organization for Economic Co-operation and Development (OECD). *Structural Analysis (STAN) Database*; OECD Publishing: Paris, France.
14. European Commission. *European Union Emissions Trading System (EU ETS) Data Viewer*; Directorate-General for Climate Action: Brussels, Belgium.
15. Eurostat. *Patent Applications to the European Patent Office (EPO) by Priority Year*; European Commission: Luxembourg.
16. Organization for Economic Co-operation and Development (OECD). *Air Emissions Accounts*; OECD Publishing: Paris, France.
17. Organization for Economic Co-operation and Development (OECD). *Environmental Policy Stringency Index (EPS)*; OECD Publishing: Paris, France.
18. Greenstone, M. The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments. *J. Polit. Econ.* **2002**, *110* (6), 1175–1219.
19. Hall, B. H.; Lotti, F.; Mairesse, J. *Innovation and Productivity in SMEs: Empirical Evidence for Italy*; NBER Working Paper No. 17329; National Bureau of Economic Research: Cambridge, MA, 2011.

■ Authors

Chris Kumala is a student at Rangitoto College with a strong interest in the intersection of economics and sustainability. His academic focus centers on endogenous growth theory and the circular economy, particularly how economic systems can drive long-term innovation while supporting environmental sustainability.

■ Appendix

Appendix A: Sample Construction		
Step	Productivity	Innovation
Raw observations	1078	1078
EU ETS merge	1001	1001
Missing employment/value added exclusions	987	987
Patent missing exclusions	987	975
Lag losses	858	846
Final TWFE	383	375
Final Event Study	987	975