# Balancing Growth and Green: Analyzing the Economic-Environmental Trade-offs Through Chinese Secondary Industry

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# Balancing Growth and Green: Analyzing the Economic-Environmental Trade-offs Through Chinese Secondary Industry

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*This paper investigates the Chinese secondary industry, revealing two significant findings through the integration of neoclassical economic theory and contemporary quasi-experimental methods. Firstly, it reveals that stringent environmental regulations can result in substantial economic losses, underscoring the trade-off between environmental regulation and economic prosperity. Secondly, it identifies an inverted U-shaped relationship between environmental regulation and economic output, indicating the existence of an optimal regulation level where environmental quality and economic growth are balanced. In light of the ongoing emphasis on sustainability, this paper suggests that it is possible to formulate regulatory policies that align economic and environmental goals, especially in developing countries under global economic pressures.*

*JEL: Q53, Q56, Q58*
*Keywords: Environmental Regulation, Sustainability, Command-and-control, Porter's hypothesis*

In modern society, achieving a delicate balance between economic output and environmental well-being is of paramount importance. Rapid industrialization

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and excessive resource consumption underscore the urgency of achieving this balance. Heavy manufacturing, a significant contributor to environmental degradation, particularly through air pollution, has far-reaching consequences. These include adverse effects on human health, diminished life satisfaction, and the exacerbation of climate change. To foster environmental sustainability, government at various levels employs a wide range of policy instruments. These encompass market-oriented mechanisms, such as carbon taxes, and command-and-control measures, including stringent emissions limitations.

The two concepts that guide scholars' efforts to determine a delicate balance and decouple economic propensity from the degradation of the environment are economic sustainability and Porter's hypothesis. While both concepts recognize that well-designed environmental regulations can achieve these goals, they operate at different levels and with distinct emphases.

The idea of economic sustainability addresses this balance from a broader, societal perspective. It aims to balance economic growth with environmental protection by emphasizing long-term viability. Some of the methods based on this concept are investing in renewable energy and implementing circular economy practices.

Porter's hypothesis, on the other hand, specifically addresses the interplay between environmental policies and a firm's competitiveness. Introduced by economist Michael Porter, it challenges the traditional view that environmental regulations necessarily harm a firm's performance. Instead, well-designed environmental policies can lead to positive outcomes for firms, such as the reduction of operational inefficiency, productivity gains, and increased innovation (Baudry, 2020).

This paper uses an integrated framework to unravel the relationship between environmental protection and economic propensity. It contributes to the literature both theoretically and empirically. Theoretically, it is one of the first studies that explore the second-order condition between economic output and pollution abatement. By estimating the marginal abatement cost before and after the enforcement of various emission limitation levels under the same policy, a concave relationship between the level of pollution abatement and the economic output is found. Therefore, we conclude that it is feasible to find a (theoretical) optimal emission cap through the production function approach. In other words, it is possible to achieve economic sustainability when the marginal production output reaches zero.

This study also provides new empirical evidence on the ongoing Porter's hypothesis debate. The results support the traditional view of economists that environmental regulation will reduce business competitiveness. The finding is aligned with the common belief that environmental protection is costly to firms required to comply with government regulations. The cost of regulatory compliance greatly exceeds the regulation-driven "innovation offsets", resulting in net economic losses.

An additional noteworthy aspect is that this empirical analysis is conducted in China, the largest developing nation that serves as a compelling case study for exploring the competing priorities between economic interest and environmental quality. Its "miracle of economic growth", with an average annual GDP growth between 8% and 12% in most years from 1978 to 2018, has come at a significant environmental cost due to the consumption of fossil fuels, such as coal (Guo, 2023). Notably, China surpassed the United States in greenhouse gas emissions in 2007 and in energy consumption in 2009, solidifying its position as the world's largest energy consumer and top climate polluter (British Petroleum, 2018).

## I. Literature Review

The impact of environmental regulations on firms' ability to compete has been a longstanding area of discussion. In our contemporary world, the relevance of this debate has intensified. The urgent need for sustainable practice has become a central concern globally. Climate change, resource depletion, and pollution necessitate responsible environmental stewardship.

The traditional view of economists is that environmental regulation imposes cost on firms, thus reducing their profitability and performance. More technically, government regulation, such as pollution abatement mandate, puts an additional constraint on the production possibility set, thus forcing profit-maximizing firms to reduce profitability (Palmer et al., 1995). The American economist Michael E. Porter (1991) introduced a new perspective to this debate, claiming that stringent environmental regulation (if well-designed and efficiently executed) would not only increase social welfare but also have a positive effect on innovations and productivity gains of firms. Porter & Linde (1995) further elaborate on this idea in one of the most cited papers in the field of business and environment.

As summarized by Jaffe & Palmer (1997), Porter's hypothesis generally takes on one of the following forms:

1) The weak version: well-designed environmental regulation will lead to innovations for which the opportunity cost surpasses the direct benefits to the firm.
2) The strong version: innovation leads to better business performance because the benefits of such innovation outweigh the cost of compliance.
3) The narrow version: market-based and performance-based regulations give firms greater incentives to innovate and will have less adverse impact on productivity than command-and-control approaches.

This paper focuses on the strong version of Porter's hypothesis, the most controversial of the three forms. From the theoretical perspective, the strong version, which implies firms will only improve financial performance under government regulations, contradicts the neoclassical economic assumption of profit maximization. From the empirical perspective, there is considerable heterogeneity in both the sign and significance level of the estimated effect size on performance. Ambec et al. (2013) provides a survey of studies that directly tests the strong version of Porter's hypothesis and attributes the divergent results to types of regulatory approaches, pollution being addressed, the research methodology, and the firm's sector. Thus, it concludes that more recent studies tend to support Porter's hypothesis compared to earlier work. Cohen & Tubb (2018) conducts a systemic meta-analysis of 107 empirical studies and concludes there is a greater likelihood of finding evidence that supports Porter's hypothesis from macro-level datasets (country, region, etc.) than from individual-level micro datasets (firm, facility, etc.).

Previous empirical research examining Porter's hypothesis generally falls into two distinct categories: one group employs a purely data-driven approach, while the other constructs an economic model based on a specific functional form and then estimates the parameters with econometric methods. For example, Benatti et al. (2024) uses local projections (LP), a data-driven model, to capture the dynamic causal effects of environmental regulation. Studies employing the difference-in-differences method, such as Li et al. (2024) also fall into this category. On the other hand, Wang et al. (2018) assumes a Cobb-Douglas functional form to investigate the link between firm output and emissions. Alpay et al. (2002) adopts a translog flexible form and estimates a short-run restricted profit function to examine the productivity growth of American and Mexican manufacturers. This paper falls more closely to the second group as the entire analysis is based on the production function approach.

## II. Policy Background

China's industrial sector, commonly known as the secondary industry, has long been recognized as a major contributor to pollution. Air pollution primarily results from coal combustion; activities such as coal-fired power generation and coal mining have exacerbated climate change, leading to further environmental degradation (Myllyvirta, 2021). In response, the Chinese government has established increasingly stringent policies targeting industrial waste gas at various legislative levels. One of the key pollutants being addressed is sulfur dioxide ($SO_2$), a corrosive and acidic gas predominantly produced by the combustion of coal or crude oil. A vast body of literature has reported the harmful effects of $SO_2$, including damage to respiratory and cardiovascular systems (Heaviside et al., 2021) and lower life satisfaction (Ferreira et al., 2013).

China's attempt to address $SO_2$ emissions from industrial facilities started from GB13223-1991, a guideline to limit sulfur dioxide from thermal power plants. In the same year, the emission standard of $SO_2$ concentration in coal-burning boilers was officially established under Standard GB13271-91, with a maximum allowable $SO_2$ concentration of 1800 mg/m$^3$. In 2001, a revision of the standard lowered the limit to 1200 mg/m$^3$. GB13271-2014 further eased the $SO_2$ emission constraint. Table 1 summarizes the historical versions of the national $SO_2$ emission standard for coal-burning boilers and the corresponding national maximum allowance level.

One thing to notice is that GB13271-2014 further separated its emission standard into different parts based on the boiler's geographic location, as demonstrated by Table 2. This version also specifies a 200 mg/m$^3$ sulfur dioxide limitation for so-called key regions. As summarized in Table 3, the scope and effective time of the 200 mg/m$^3$ limitation is determined by the provincial government or the provisions of the environmental protection administrative department. Figure 1 describes the effective sulfur dioxide emission limitation as of 2017.

| **Year** | **Standard No.** | **Maximum Allowance (mg/m$^3$)** |
|---|---|---|
| 1992 | GB13271-91 | 1800 |
| 2001 | GB13271-2001 | 1200 |
| 2014 | GB13271-2014 | 550 |

Table 1—Historical Versions of GB13271

| **Effective Date** | **Limitation (mg/m$^3$)** | **Province** |
|---|---|---|
| July 1st, 2016 | 550 | Guangxi, Chongqing, Sichuan, Guizhou |
| July 1st, 2016 | 400 | All but the last four provinces |

Table 2—GB13271-2014 Nationwide $SO_2$ Emission Standard

| **Effective Date** | **Maximum Allowance (mg/m$^3$)** | **Province** |
|---|---|---|
| September 1st, 2007 | 200 | Beijing |
| October 1st, 2014 | 200 | Shanghai |
| January 1st, 2015 | 200 | Shandong |
| August 1st, 2016 | 200 | Tianjin |

Table 3—Effective Date of 200 mg/m$^3$ $SO_2$ Limitation in Key Region

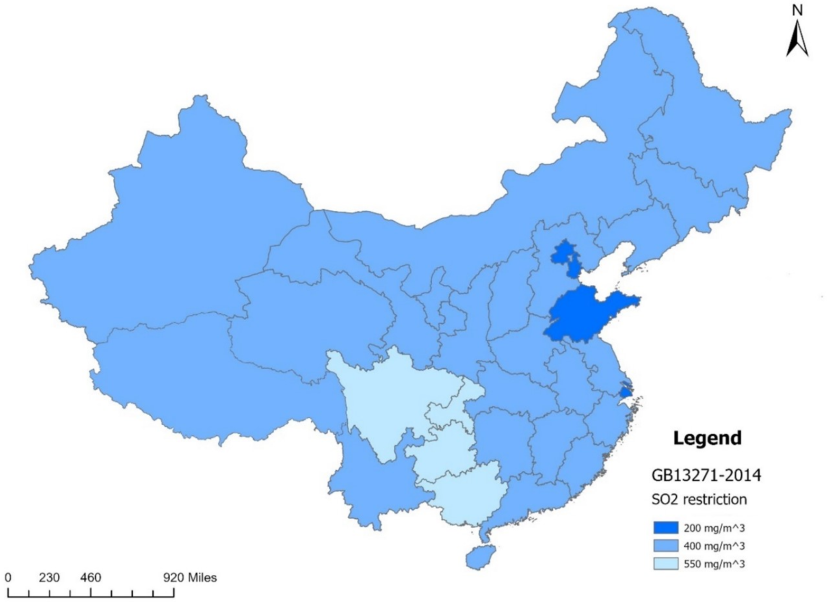

Figure 1. Sulfur Dioxide Limitation Level by Province in 2017

## III. Data

We compiled a balanced panel dataset comprised of 434 observations across 31 provinces from 2004 to 2017. The primary data source was the National

Bureau of Statistics of China (NBS) China Statistical Yearbook, supplemented by secondary data from China World Development Indicators provided by the World Bank. The Consumer Price Index (CPI) was obtained directly from the secondary source, using a base year of 2010. All other variables were sourced directly from the NBS. A summary of each variable is presented in Table 4.

| VARIABLES | (1)<br>N | (2)<br>mean | (3)<br>sd | (4)<br>min | (5)<br>max |
|---|---|---|---|---|---|
| CPI | 434 | 1.026 | 0.114 | 0.850 | 1.191 |
| Real_Capital | 434 | 8,531 | 9,897 | 27.44 | 57,730 |
| Real_IGRP | 434 | 6,020 | 5,823 | 18.15 | 29,635 |
| SO2 | 434 | 60.70 | 40.81 | 0.0787 | 182.7 |
| Employee | 434 | 167.1 | 171.4 | 1.522 | 1,431 |
| Year | 434 | 2,010 | 4.036 | 2,004 | 2,017 |
| cap_200 | 434 | 0.0392 | 0.194 | 0 | 1 |
| cap_400 | 434 | 0.0622 | 0.242 | 0 | 1 |
| interact_200 | 434 | 0.0902 | 0.509 | 0 | 5.028 |
| interact_400 | 434 | 0.176 | 0.752 | -1.050 | 4.303 |
| log_capital | 434 | 8.422 | 1.297 | 3.312 | 10.96 |
| log_emission | 434 | 3.664 | 1.329 | -2.542 | 5.208 |
| log_labor | 434 | 4.637 | 1.166 | 0.420 | 7.266 |
| log_output | 434 | 8.134 | 1.319 | 2.899 | 10.30 |

Table 4—Summary Statistics

We employed the real Industry Gross Regional Product (real GRP) as a proxy for the output variable. This measure was derived from the Industry Gross Regional Product Value, which was then deflated using the CPI. The final variable, *Real_IGPR*, is reported in units of 100 million yuan.

Similarly, we used the deflated total current assets reported in the table "Main Indicators of All State-owned and Non-state-owned Industrial Enterprises Above Designated Size" as a proxy for capital. The final variable, *Real_Capital*, is also reported in units of 100 million yuan.

For the labor variable, we combined the number of employed persons in urban units across three sectors: mining, manufacturing, and the production and distribution of electricity, gas, and water. The labor input, *Employee*, is measured in units of $10,000$ persons.

Sulfur dioxide emission data, represented by the variable $SO_2$, was collected from the table "Emission and Treatment of Industrial Waste Gas by Region" and is reported in units of $10,000$ tons.

Additionally, we created dummy variables to represent the enforcement of regulations at specific stringency levels within a given province during a particular year. Specifically, *Cap_400* takes the value 1 when a maximum allowance of 400 mg/m$^3$ of sulfur dioxide is enforced, and 0 if it is not. The same rule applies to *Cap_200*.

## IV. Estimation Framework

Following the work of others, we estimate a production function that takes emission as an input to guide our empirical investigation (e.g. Copeland & Taylor, 2003; Cropper & Oates, 1992; Wang et al., 2018). According to the formal proof by Ebert and Welsch (2007), there is no distinction between estimating an explicit emission function and considering emissions as a production input in the context of mathematical modeling. Technology can equivalently be described by either a well-behaved production function with emissions as an input, or a well-behaved emission function if the materials balance is accounted for as an additional condition.

Consider a three-input Cobb-Douglas production function with emission, capital, and labor as input:

$$Y = f(E, K, L) = AE^{\beta_1}K^{\beta_2}L^{\beta_3} \tag{1}$$

Then we take the log transformation to meet the OLS assumption of linearity in the parameter:

$$\ln(Y) = \ln(A) + \beta_1 \ln(E) + \beta_2 \ln(K) + \beta_3 \ln(L) \tag{2}$$

Then we can get a specification with the standard two-way fixed effect to conduct the comparative static analysis:

$$Y_{it} = \beta_0 + \beta_1 e_{it} + \beta_2 k_{it} + \beta_3 l_{it} + \alpha_i + \nu_t + \epsilon_{it} \tag{3}$$

where the lowercase symbols represent natural logs of input variables.

To evaluate how emission limitations affect the marginal impact of emissions on output, we introduced a dummy variable and an interaction term, leading to the following specification:

$$Y_{it} = \beta_0 + \beta_1 e_{it} + \beta_2 k_{it} + \beta_3 l_{it} + \beta_4 \theta_{it} + \beta_5 (\theta_{it} \cdot e_{it}) + \alpha_i + \nu_t + \epsilon_{it} \tag{4}$$

The estimated coefficients for this specification are presented in Columns (1) and (2) of Table 5. Column (1) indicates that, in the absence of regulation, on average, a one percent increase in emissions leads to an output decrease of $224,600$ million yuan. Following the enforcement of a medium restriction (400 mg/m$^3$) on sulfur dioxide emissions, a one percent increase in emissions leads to an output decrease of $128,190$ million yuan. Similarly, Column (2) shows that after implementing a strong restriction (200 mg/m$^3$) on sulfur dioxide emissions, a one percent increase in emissions results in an output decrease of $62,800$ million yuan. A comprehensive explanation of the regression interpretation can be found in Table 6. This interpretation framework is consistently applied to the remaining regression results.

Figure 2 presents the interpretation of the regression result through the difference -in-differences approach. The treatment is the emission limitation enforced at each level, while the outcome variable is economic output. We can see that the slope of the regression line gradually decreases after the enforcement of more stringent regulation. Thus, the y-intercept of the regression line gradually decreases as we tighten the emission restriction. From these findings, we can draw the following conclusions:

1) Environmental regulation negatively impacts economic output.
2) More stringent emission limitations lead to a further absolute decrease in economic output.
3) The marginal effect of pollution abatement on economic output diminishes with more stringent regulations.

Figure 3 demonstrates the concave relationship we found between the level of pollution abatement and the economic output. This graph directly reflects the third conclusion we have drawn previously, that the magnitude of the estimated parameters of pollution abatement decreases as regulatory stringency level increases. Based on optimization theory, we infer that there exists an interior solution representing the optimal emission cap. In other words, when the marginal effect of pollution abatement is zero, we reach the optimal emission limitation. Figure 5 describes the findings where the additional benefits gained from reducing pollution diminish as more abatement efforts are made. The x-intercept represents the theoretical optimal regulatory stringency.

To relax the assumption of the province-specific and time-fixed effects, we also estimated a pooled OLS model with the results reported in Column (3) and (4) in Table 5. Table 7 provides a step-by-step interpretation of the results. While there is a sign change in the marginal effect of pollution abatement following the enforcement of the 200 mg/m$^3$ emission cap, our earlier conclusion regarding concavity remains consistent. Figure 4 illustrates that the optimal emission limitation in this scenario falls within the range of 200 to 400 mg/m$^3$.

The finding of this concave relationship seems to be connected to the widely recognized Environmental Kuznets Curve (EKC), although it diverges in its underlying premise. The EKC, initially proposed in the field of development economics, depicts an inverted U-shaped association between per capita income and environmental pollution. It highlights the interplay between economic growth and environmental degradation. In contrast, the inverted U-shaped curve identified in this study specifically reflects the relationship between pollution abatement and production output.

Figure 2. Interpretation of Regression Result through Difference-in-Differences Approach

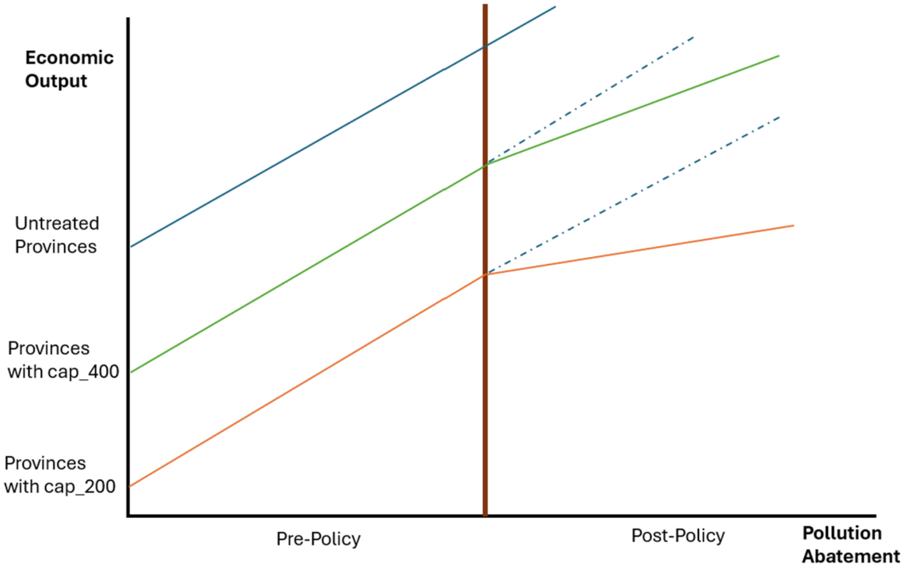

Table 5—Linear-log Model with Two Way Fixed Effect and Pooled OLS

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Real_IGRP | Real_IGRP | Real_IGRP | Real_IGRP |
| | cap_400 | cap_200 | cap_400 | cap_200 |
| log_emission | -2,246*** | -2,891*** | -1,461*** | -1,909*** |
| | (272.9) | (282.0) | (285.3) | (253.3) |
| log_labor | 4,859*** | 4,148*** | 3,211*** | 3,249*** |
| | (468.6) | (454.0) | (582.4) | (568.9) |
| log_capital | 35.56 | -98.32 | 1,633*** | 1,968*** |
| | (375.1) | (360.4) | (431.1) | (411.0) |
| cap_400 | -2,853*** | | -5,014** | |
| | (991.7) | | (2,498) | |
| interact_400 | 964.1*** | | 1,302 | |
| | (219.8) | | (831.1) | |
| cap_200 | | -6,952*** | | -17,477*** |
| | | (1,012) | | (1,522) |
| interact_200 | | 2,263*** | | 5,326*** |
| | | (321.0) | | (508.4) |
| Constant | -10,992*** | -4,466 | -17,186*** | -18,418*** |
| | (3,319) | (3,293) | (1,870) | (1,714) |
| Observations | 434 | 434 | 434 | 434 |
| R-squared | 0.724 | 0.744 | 0.621 | 0.681 |
| Provinces Fixed Effect | YES | YES | NO | NO |
| Year Fixed Effect | YES | YES | NO | NO |

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 3. Concavity Case 1

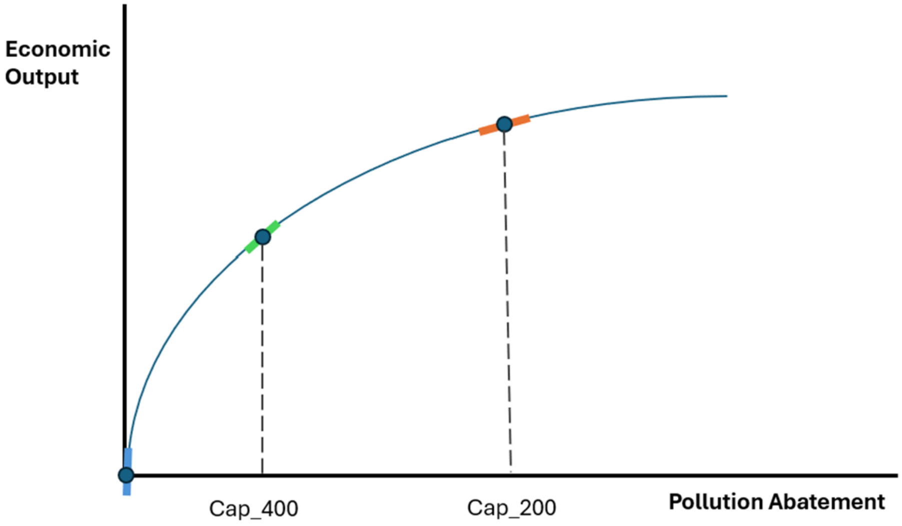

Figure 4. Concavity Case 2

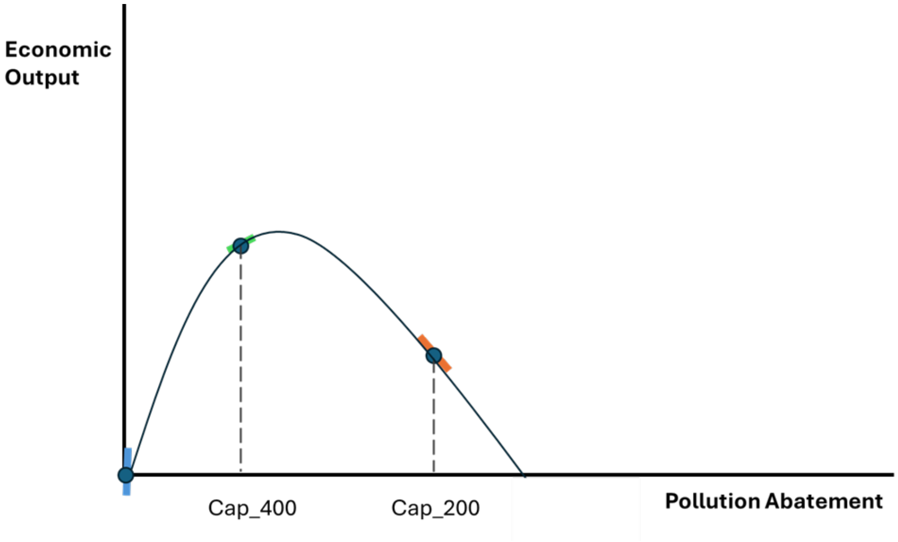

Figure 5. Diminishing Return of Abatement

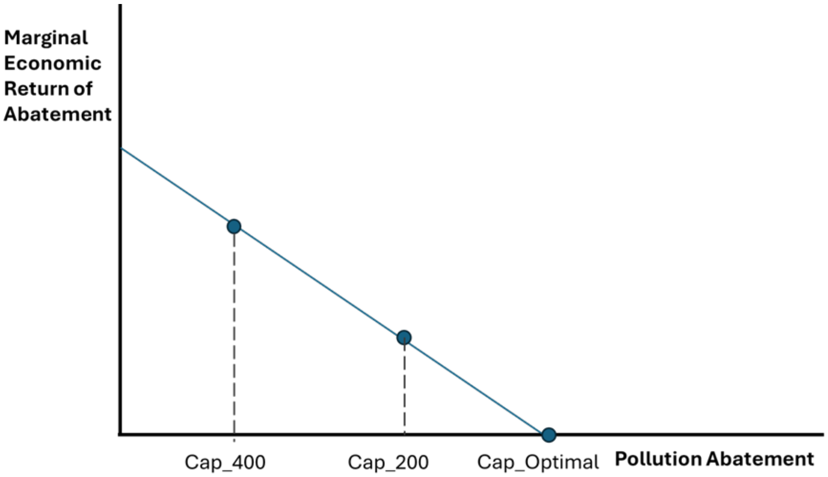

Table 6—Interpretation of Regression Results (1) and (2)

| **Emission** | **No Cap** | **Cap_400** | **Cap_200** |
|---|---|---|---|
| **Pollution Abatement Level** | No Abatement | Medium Abatement | High Abatement |
| **Baseline Effect of Emission Abatement** | Baseline | Economic output decreases of 2,853 | Economic output decreases of 6,952 |
| **Average Marginal Effect of Emission on Output** | A one percent increase in emission will lead to an output decrease of 2,891. | A one percent increase in emission will lead to an output decrease of 1,280. | A one percent increase in emission will lead to an output decrease of 628. |
| **Average Marginal Effect of Abatement on Output** | A one percent decrease in abatement will lead to an output decrease of 2,891. | A one percent decrease in abatement will lead to an output decrease of 1,280. | A one percent decrease in abatement will lead to an output decrease of 628. |
| **Average Marginal Effect of Abatement on Output** | A one percent increase in abatement will lead to an output increase of 2,891. | A one percent increase in abatement will lead to an output increase of 1,280. | A one percent increase in abatement will lead to an output increase of 628. |

Table 7—Interpretation of Regression Results (3) and (4)

| **Emission** | **No Cap** | **Cap_400** | **Cap_200** |
|---|---|---|---|
| **Pollution Abatement Level** | No Abatement | Medium Abatement | High Abatement |
| **Baseline Effect of Emission Abatement** | Baseline | Economic output decreases of 5,014 | Economic output decreases of 17,477 |
| **Average Marginal Effect of Emission on Output** | A one percent increase in emission will lead to an output decrease of 1,909. | A one percent increase in emission will lead to an output decrease of 159. | A one percent increase in emission will lead to an output increase of 3,417. |
| **Average Marginal Effect of Abatement on Output** | A one percent decrease in abatement will lead to an output decrease of 1,909. | A one percent decrease in abatement will lead to an output decrease of 159. | A one percent decrease in abatement will lead to an output decrease of 3,417. |
| **Average Marginal Effect of Abatement on Output** | A one percent increase in abatement will lead to an output increase of 1,909. | A one percent increase in abatement will lead to an output increase of 159. | A one percent increase in abatement will lead to an output decrease of 3,417. |

## V. Conclusion

In summary, our analysis integrates concepts from neoclassical economic theory and contemporary quasi-experimental methodologies. From this synthesis, we derive two noteworthy findings. First, stringent environmental regulations lead to considerable economic losses, which rejects Porter's hypothesis. Second, our investigation reveals a concave relationship between environmental regulation and economic output. Although the first finding highlights a significant trade-off between environmental regulation and economic prosperity, the second implies that there exists an optimal level of regulation –a delicate balance –where environmental quality and economic growth align harmoniously.

Besides offering new empirical evidence to evaluate Porter's hypothesis, this study offers new insight into balancing short-term economic gains and long-term environmental consequences, especially in developing countries. These nations often prioritize rapid economic growth as a means to alleviate poverty, enhance living standards, and create employment opportunities. In addition, they face global pressures to compete economically, and such pressure overshadows environmental concerns. However, unchecked industrial expansion and exploitation of natural resources, while temporarily boosting GDP, can inflict harm on ecosystems and public health, resulting in additional costs to mitigate the environmental damage and climate change. Given the ongoing call for sustainability, this study explores the feasibility of developing regulatory policies that harmonize both economic and environmental objectives. Again, integrating these seemingly competing goals in the design of pollution control restrictions is indeed practicable.

## VI. Robustness Check

The theoretical finding of this paper is strongly robust to different functional forms and linear regression models. To assess the robustness of our results with respect to functional form, we applied a logarithmic transformation to both sides of the Cobb-Douglas production function, resulting in the following equation:

$$\ln(Y) = \ln(A) + \beta_1 \ln(E) + \beta_2 \ln(K) + \beta_3 \ln(L) \tag{5}$$

The corresponding econometric specification that estimates the policy effect is:

$$y_{it} = \beta_0 + \beta_1 e_{it} + \beta_2 k_{it} + \beta_3 l_{it} + \beta_4 \theta_{it} + \beta_5 (\theta_{it} \cdot e_{it}) + \alpha_i + \nu_t + \epsilon_{it} \tag{6}$$

In line with Table 5, Table 8 presents the estimated parameters derived from the two-way fixed effects model and the pooled OLS model. Despite the lack of statistical significance for the parameters of interest, our conclusion regarding absolute economic loss resulting from emission limitations and the inverted U-shaped curve between abatement level and economic output remains valid.

Similarly, we implemented various linear regression models to assess the robustness of our findings with respect to statistical modeling.

First, as reported in Table 9, we relaxed the assumption of the year-fixed effect that accounts for the common time shocks affecting all provinces within a specific year. We also implemented a random effects model that treats unobserved province-specific effects as random and uncorrelated with the explanatory variable.

In addition, we conducted the Hausman test to validate the suitability of including province-level fixed effects in our main analysis. With a p-value of 0.0001 for cap_400 models and 0.0000 for cap_200 models, the initial hypothesis that the province-level effects are adequately modeled by a random-effects model is resoundingly rejected. Therefore, a model incorporating province fixed effects is more reliable in this case. Table 10 reports the estimated parameters from a linear mixed model. Again, the theoretical result is highly robust to alternative panel regression models.

Table 8—Log-Log Model with TWFE and Pooled OLS

| VARIABLES | (5)<br>log_output<br>cap_400 | (6)<br>log_output<br>cap_200 | (7)<br>log_output<br>cap_400 | (8)<br>log_output<br>cap_200 |
|---|---|---|---|---|
| log_emission | 0.0123 | -0.00902 | 0.114*** | 0.102*** |
| | (0.0265) | (0.0284) | (0.0177) | (0.0180) |
| log_labor | 0.238*** | 0.217*** | 0.510*** | 0.506*** |
| | (0.0455) | (0.0457) | (0.0527) | (0.0531) |
| log_capital | 0.371*** | 0.373*** | 0.473*** | 0.487*** |
| | (0.0364) | (0.0363) | (0.0422) | (0.0431) |
| cap_400 | -0.135 | | -0.138 | |
| | (0.0963) | | (0.149) | |
| interact_400 | -0.0219 | | 0.00789 | |
| | (0.0214) | | (0.0457) | |
| cap_200 | | -0.161 | | -0.358*** |
| | | (0.102) | | (0.109) |
| interact_200 | | 0.00164 | | 0.0419 |
| | | (0.0323) | | (0.0276) |
| Constant | 3.425*** | 3.581*** | 1.379*** | 1.322*** |
| | (0.322) | (0.332) | (0.165) | (0.169) |
| Observations | 434 | 434 | 434 | 434 |
| R-squared | 0.910 | 0.910 | 0.951 | 0.951 |
| Provinces Fixed Effect | Yes | Yes | No | No |
| Year Fixed Effect | Yes | Yes | No | No |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9—Linear-Log Model with One-Way Fixed Effect and Random Effect

| | (9) | (10) | (11) | (12) |
|---|---|---|---|---|
| VARIABLES | log_output | log_output | log_output | log_output |
| log_emission | -1,490*** | -1,870*** | -982.0*** | -1,503*** |
| | (250.6) | (227.5) | (256.7) | (210.1) |
| log_labor | 6,554*** | 5,398*** | 5,301*** | 4,286*** |
| | (438.3) | (374.2) | (438.5) | (346.7) |
| log_capital | 1,458*** | 1,470*** | 1,402*** | 1,430*** |
| | (163.5) | (167.5) | (173.6) | (178.1) |
| cap_400 | -5,936*** | -5,526*** | | |
| | (833.8) | (850.8) | | |
| interact_400 | 1,103*** | 1,025*** | | |
| | (251.8) | (257.9) | | |
| cap_200 | | | -4,223*** | -5,683*** |
| | | | (1,241) | (1,241) |
| interact_200 | | | 1,638*** | 2,000*** |
| | | | (397.0) | (402.1) |
| Constant | -31,009*** | -24,374*** | -26,749*** | -20,347*** |
| | (2,208) | (1,790) | (2,367) | (1,651) |
| Observations | 434 | 434 | 434 | 434 |
| Number of Region | 31 | 31 | 31 | 31 |
| Provinces Effect | Fixed | Random | Fixed | Random |
| Year Fixed Effect | No | No | No | No |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10—Linear-Log Model with Mix Effects

| VARIABLES | (13)<br>Real_IGRP cap_400 | (14)<br>Real_IGRP cap_200 |
|---|---|---|
| log_emission | -2,102*** | -2,465*** |
|  | (247.0) | (247.9) |
| log_labor | 5,032*** | 4,879*** |
|  | (386.0) | (365.2) |
| log_capital | 114.5 | 227.0 |
|  | (347.4) | (336.1) |
| cap_400 | -2,905*** |  |
|  | (993.2) |  |
| interact_400 | 986.9*** |  |
|  | (219.5) |  |
| cap_200 |  | -6,513*** |
|  |  | (999.2) |
| interact_200 |  | 2,173*** |
|  |  | (323.6) |
| Constant | -12,883*** | -11,726*** |
|  | (2,359) | (2,129) |
| Observations | 434 | 434 |
| Number of Region | 31 | 31 |
| Provinces Effect | Random | Random |
| Year Effect | Fixed | Fixed |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## REFERENCES

Alpay, E., Kerkvliet, J., & Buccola, S. (2002). Productivity Growth and Environmental Regulation in Mexican and U.S. Food Manufacturing. *American Journal of Agricultural Economics*, 84(4), 887–901. `https://doi.org/10.1111/1467-8276.00041`

Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2013). The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? *Review of Environmental Economics and Policy*, 7(1), 2–22. `https://doi.org/10.1093/reep/res016`

Barbier, E. B. (1987). The Concept of Sustainable Economic Development. *Environmental Conservation*, 14(2), 101–110. `https://doi.org/10.1017/S0376892900011449`

Barbier, E. B. (2012). The Green Economy Post Rio+20. *Science*, 338(6109), 887–888. `https://doi.org/10.1126/science.1227360`

Barron, P., Cord, L., Cuesta, J., Espinoza, S. A., Larson, G., & Woolcock, M. (2023). Social Sustainability and the Development Process: What is it, why does it Matter, and How can it be Enhanced? *The World Bank*. `https://doi.org/10.1596/1813-9450-10487`

Baudry, M. (2020). The Porter's Hypothesis and its Implications for the Acceptability of Ambitious National Climate Policies. In K. F. Zimmermann (Ed.), *Handbook of Labor, Human Resources and Population Economics* (pp. 1–20). Springer International Publishing. `https://doi.org/10.1007/978-3-319-57365-6_259-1`

Benatti, N., Groiss, M., Kelly, P., & Lopez-Garcia, P. (2024). Environmental regulation and productivity growth in the euro area: Testing the porter hypothesis. *Journal of Environmental Economics and Management*, 126, 102995. `https://doi.org/10.1016/j.jeem.2024.102995`

Cohen, M. A., & Tubb, A. (2018). The Impact of Environmental Regulation on

Firm and Country Competitiveness: A Meta-analysis of the Porter Hypothesis. *Journal of the Association of Environmental and Resource Economists*, 5(2), 371–399. `https://doi.org/10.1086/695613`

Copeland, B. R., & Taylor, M. S. (2003). Trade, Growth and the Environment (Working Paper 9823). *National Bureau of Economic Research.* `https://doi.org/10.3386/w9823`

Cropper, M. L., & Oates, W. E. (1992). Environmental Economics: A Survey. *Journal of Economic Literature*, 30(2), 675–740.

Doane, D., & Macgillivray, A. (2001). Economic Sustainability The business of staying in business. `https://api.semanticscholar.org/CorpusID:167607706`

Ferreira, S., Akay, A., Brereton, F., Cuñado, J., Martinsson, P., Moro, M., & Ningal, T. F. (2013). Life satisfaction and air quality in Europe. *Ecological Economics*, 88, 1–10. `https://doi.org/10.1016/j.ecolecon.2012.12.027`

Foladori, G. (2005). Advances and Limits of Social Sustainability as an Evolving Concept. *Canadian Journal of Development Studies/Revue Canadienne d'études Du Développement*, 26(3), 501–510. `https://doi.org/10.1080/02255189.2005.9669070`

Heaviside, C., Witham, C., & Vardoulakis, S. (2021). Potential health impacts from sulphur dioxide and sulphate exposure in the UK resulting from an Icelandic effusive volcanic eruption. *Science of The Total Environment*, 774, 145549. `https://doi.org/10.1016/j.scitotenv.2021.145549`

IBM. (2024, January 19). What is Environmental, Social, and Governance (ESG)? `https://www.ibm.com/topics/environmental-social-and-governance`

Jaffe, A. B., & Palmer, K. (1997). Environmental Regulation and Innovation: A Panel Data Study. *The Review of Economics and Statistics*, 79(4), 610–619. `https://doi.org/10.1162/003465397557196`

Kajikawa, Y., Tacoa, F., & Yamaguchi, K. (2014). Sustainability science: The changing landscape of sustainability research. *Sustainability Science*, 9(4), 431–438. `https://doi.org/10.1007/s11625-014-0244-x`

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: Building a new discipline. *Sustainability Science*, 1(1), 1–6. `https://doi.org/10.1007/s11625-006-0007-4`

Li, P., Wu, J., & Xu, W. (2024). The impact of industrial sulfur dioxide emissions regulation on agricultural production in China. *Journal of Environmental Economics and Management*, 124, 102939. `https://doi.org/10.1016/j.jeem.2024.102939`

Lubchenco, J., Olson, A. M., Brubaker, L. B., Carpenter, S. R., Holland, M. M., Hubbell, S. P., Levin, S. A., MacMahon, J. A., Matson, P. A., Melillo, J. M., Mooney, H. A., Peterson, C. H., Pulliam, H. R., Real, L. A., Regal, P. J., & Risser, P. G. (1991). The Sustainable Biosphere Initiative: An Ecological Research Agenda: A Report from the Ecological Society of America. *Ecology*, 72(2), 371–412. `https://doi.org/10.2307/2937183`

Mebratu, D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, 18(6), 493–520. `https://doi.org/10.1016/S0195-9255(98)00019-5`

Moldan, B., Janoušková, S., & Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, 17, 4–13. `https://doi.org/10.1016/j.ecolind.2011.04.033`

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, 1(1), 1–10. `https://doi.org/10.14448/jes.01.0002`

Myllyvirta, L. (2021, May 20). Analysis: China's carbon emissions grow at fastest rate for more than a decade. *Carbon Brief*. `https://www.carbonbrief.org/analysis-chinas-carbon-emissions`

Palmer, K., Oates, W. E., & Portney, P. R. (1995). Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm? *Journal of Economic Perspectives*, 9(4), 119–132. `https://doi.org/10.1257/jep.9.4.119`

Porter, M. E., & Linde, C. V. D. (1995). Toward a New Conception of the Environment-Competitiveness Relationship. *Journal of Economic Perspectives*, 9(4), 97–118. `https://doi.org/10.1257/jep.9.4.97`

Stahel, W. R. (2016). The circular economy. *Nature*, 531(7595), 435–438. `https://doi.org/10.1038/531435a`

UNEP. (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers. `https://wedocs.unep.org/xmlui/handle/20.500.11822/32245`

US EPA. (2013, July 19). National Environmental Policy Act [Overviews and Factsheets]. `https://www.epa.gov/nepa`

Wang, C., Wu, J., & Zhang, B. (2018). Environmental regulation, emissions and productivity: Evidence from Chinese COD-emitting manufacturers. *Journal of Environmental Economics and Management*, 92, 54–73. `https://doi.org/10.1016/j.jeem.2018.08.004`