

Estimating the Emission Intensity Elasticity for 10 major pollutants

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ABSTRACT. This paper estimates how the emission intensity, measured as total emissions of a pollutant per unit of real output, responds to per-capita income growth and trade variables. The objective is to understand the role policies can play in achieving balanced and sustained decoupling of pollutant emissions from economic growth. Using a long-run panel covering ten major pollutants for 145 countries (1970–2012) and two-way fixed effects, we quantify the elasticity of emission intensity with respect to income per capita. The estimated elasticities range from -0.46 to -1.02 . Trade exposure is positively correlated with emission intensity in levels but its interaction with income is negative, suggesting that openness can initially worsen pollution through composition effects yet later accelerate development of environmentally friendly techniques. A clear divide emerges between pollutants. The industrial pollutants (such as sulphur dioxide and nitrogen oxides) are relatively inelastic. Non-industrial pollutants (including ammonia and black carbon) show much higher elasticities. These findings reveal that economic development and global trade integration has shaped environmental outcomes in distinct ways across pollutants. This highlights the need for targeted policies that distinguish between pollutant types to achieve balanced and sustained decoupling of pollutant emissions from economic growth. The results suggest that regulatory framework targeting industrial emissions needs to be stricter than the one that targets non-industrial emissions

Keywords: Environmental Kuznets curve, Emission intensity, Trade and environment

JEL Codes: Q56, Q53, F8, O44, C23

INTRODUCTION

The objective of this paper is to re-visit the age-old question whether trade is good or bad for environment. If liberalised trade during the period called the Great Moderation¹ makes it easier for the richer countries to import goods that pollute the environment in stead of making them in the domestic economy, then trade could simply displace the pollution from the richer countries to the poorer ones. It may also give the poor countries an opportunity to specialise in the goods that pollute and spur economic growth at the cost to the local and global environment.

Yet, if trade leads to economic growth in the poorer countries, which in turn leads to people living in those countries to push for a cleaner local environment, then the net effect of trade could go either way for the environment. Figure 2 illustrates the cumulative growth in greenhouse gas emission and Figure 1 the changes in per-capita output distribution and other trade related variable over the 1970 the 2012 period in the 145 countries in our dataset.

The literature has traditionally decomposed the emissions produced in a country into *scale*, *composition* and *technique effect* (Copeland and Taylor, 2004; Brock and Taylor, 2005). The **scale** measures the scale of the economy, i.e., the value of goods produced in the economy, holding constant both the range of goods produced and the technology used to produce them. The **composition** is the share of the dirty or polluting sector in the economy. **Technique** refers to the production techniques used in the various sector of the economy. Emission thus increase as the scale of the economy increases.

Emission intensity is defined as total emissions of a pollutant divided by the total production output of the economy. If there is no change in the composition or techniques across the various sectors of the economy, then *emission intensity should remain constant even as the scale of the economy increases*. As the share of the dirty sector in the economy increases, emission intensity will increase through the *composition effect*. If a dirty sector adopts a cleaner technique, the emission intensity of the country will decrease through the

¹This is the period from 1980 to 2007 which saw significant changes in income distribution across the world(Bernanke, 2004).

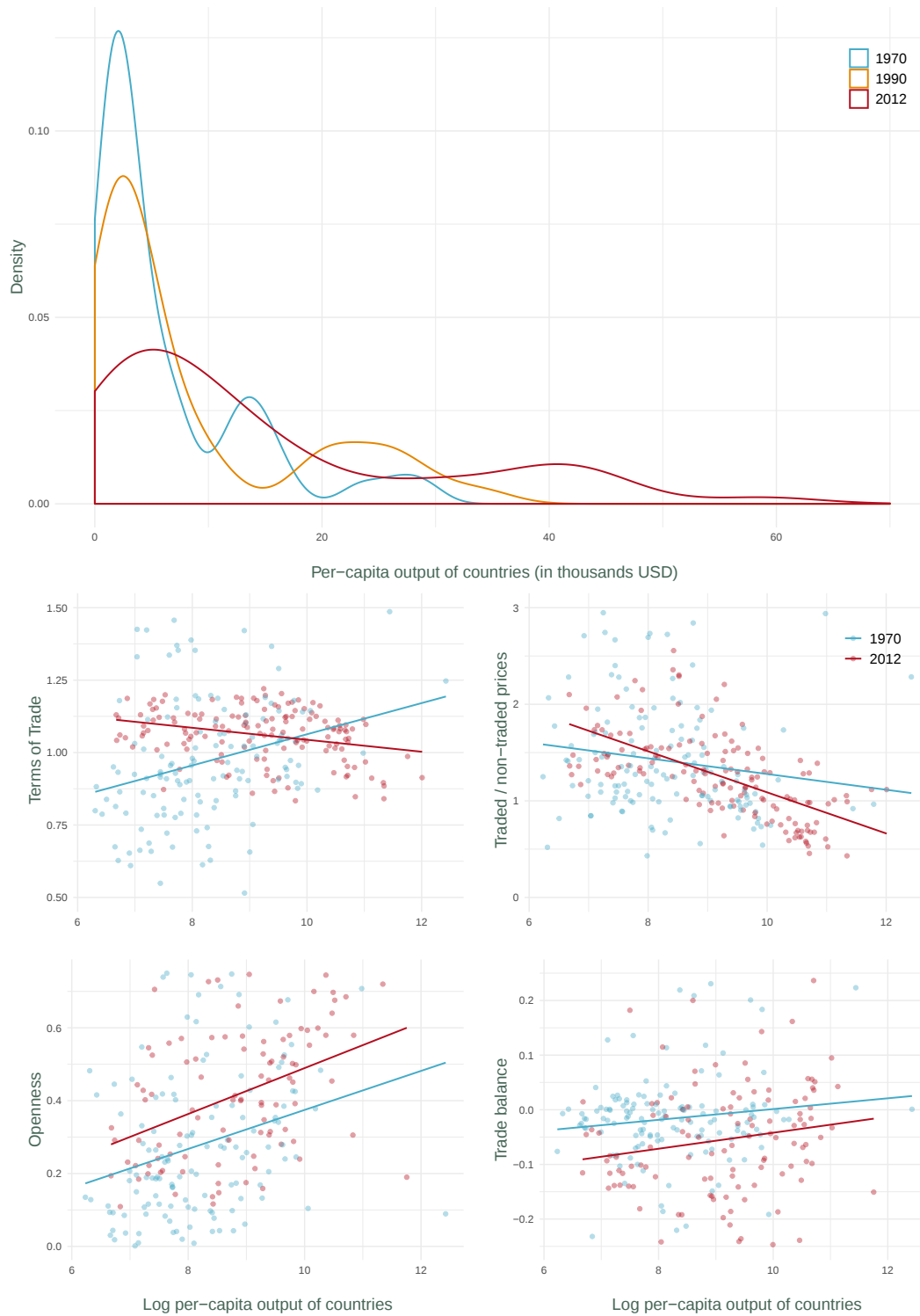


FIGURE 1. Change in per-capita output, terms of trade, ratio of traded and non-traded prices, openness and trade balance over the 1970-2012 period

technique effect, adjusting for the share of the particular dirty sector in the economy. The *technique effect*'s impact on emission intensity of the country depends on the shares of the sectors affected by it.



FIGURE 2. Cumulative Growth in global emissions over the 1970-2012 period

We use new data to examine this net effect of trade and per-capita output on 10 greenhouse gas (GHG) emissions across the world using a dataset we have collated that spans 145 countries from 1970 to 2012. Of the ten pollutants, the dataset tracks five particulate matters pollutants, i.e., Black Carbon (*bc*), Organic Carbon (*oc*), Particulate Matter with aerodynamic diameter $< 10\mu m$ (*pm10*), Particulate Matter of aerodynamic diameter $< 2.5\mu m$ from fossil fuel sources and Particulate Matter of aerodynamic diameter $< 2.5\mu m$ from biological fuel sources. The dataset also tracks five Gaseous pollutants, i.e., Carbon monoxide (*co*), Sulfur dioxide (*so2*), Non-methane volatile organic compounds (*nmvoc*), Nitrogen oxides (*nox*) and Ammonia (*nh3*) (see Table 1 below). The cumulative growth in these 10 major pollutants since 1970 has been extraordinary (see Figure).

Using fixed effects, the paper examines the impact of emission intensity of these pollutants on per-capita income and trade variable. β is the elasticity of the emission intensity of pollutants with respect to per-capita income. The paper finds that for pollutants that are

the **by-products of industrial production**, the emission intensity is relatively **inelastic** with respect to per-capita income, i.e., $-0.67 < \beta_y^{so2}, \beta_y^{nmvoc}, \beta_y^{pm25f}, \beta_y^{nox}, \beta_y^{co} < -0.54$. Conversely, for pollutants that are the **by-products of non-industrial production**, the emission intensity is relatively **elastic** with respect to per-capita income, i.e., relatively elastic, i.e., $\beta_y^{oc}, \beta_y^{pm25b}, \beta_y^{nh3} < -0.9$. For pollutants that are the **by-products of a mix of industrial and non-industrial production**, the elasticity of emission intensity with respect to per-capita income are somewhere in between, i.e., $-0.9 < \beta_y^{bc}, \beta_y^{pm10} < -0.78$ (See Tables 4 and 5).

1. DESCRIPTION OF THE DATASET

The paper compiles a balanced dataset tracking the emissions of 10 major pollutants across 145 countries from 1970 to 2012. The aim is to estimate the **technique effect** by examining the emission intensities of these pollutants. The cumulative growth of these 10 major pollutants since 1970 has been remarkable (See Figure 2). These pollutants are by-products of either *industrial production*, *non-industrial production* or a *mix of industrial and non-industrial production*. Distinguishing between these by-products partially addresses the **composition effect**.

TABLE 1. List of Pollutants and their description

Particulate Matter

<i>pm10</i>	Particulate Matter	Particles with aerodynamic diameter < 10 µm
<i>pm25b</i>	Particulate Matter	Particles of aerodynamic diameter < 2.5 µm from biological fuel sources
<i>pm25f</i>	Particulate Matter	Particles of aerodynamic diameter < 2.5 µm from fossil fuel sources
<i>bc</i>	Black Carbon	Sooty black material emitted from gas and diesel engines, coal-fired power plants, and other sources that burn fossil fuel.
<i>oc</i>	Organic carbon	Fossil and biomass fuel combustion, vegetative detritus, oxidation of gaseous organic compounds.

Gaseous emissions

<i>co</i>	Carbon monoxide	Fossil fuel combustion, particularly spark-ignition engines, oxidation of biogenic VOC emissions
<i>so2</i>	Sulfur dioxide	Emissions arise from combustion.
<i>nmvoc</i>	Non-methane volatile organic compounds	Emissions arise from combustion and use of solvents and production processes.
<i>nox</i>	nitrogen oxides	Emissions arise from combustion.
<i>nh3</i>	amonia	agriculture, including animal husbandry and nh3-based fertiliser applications, industrial processes, vehicular emissions and volatilization from soils and oceans.

2. EMPIRICS

2.1. Baseline Regressions.

2.1.1. *Definitions.* Country i 's population at time t is given by P_{it} and total real output is given by Y_{it} . The total emission from a particular pollutant j is given by E_{it}^j . Country i 's *per-capita output* is given by $y_{it} = \frac{Y_{it}}{P_{it}}$ and *emission intensity* for pollutant j at time t by $e_{it}^j = \frac{E_{it}^j}{Y_{it}}$.

Before we run the full regression, we estimate the baseline case in equation set out in (1).

$$\ln e_{it}^j = \alpha_i^j + \alpha_t^j + \bar{\beta}_y^j \cdot \ln y_{it} + \varepsilon_{it} \quad (1)$$

where for each pollutant j , the absolutely value of $\bar{\beta}_y^j$ represents pollutant j 's emission intensity's elasticity with respect to per-capita real output and α_i^j and α_t^j are individual and time effects respectively. We estimate the fixed effects in equation (1) using the panel data described above in Section 1.

The results are presented in Table 2 and 3 indicate that the emission intensity's elasticity with respect to per-capita real output for the pollutants given by $\bar{\beta}_y^j \in \{-0.78, -0.98\}$. In the baseline case, the emissions intensity declines with per-capita output in a similar manner for all pollutants. We re-run the regressions below with additional trade variables to understand how trade impacts emission intensity elasticity.

TABLE 2. Regressions for so2, nmvoc, pm25f, nox & co

	$\log \frac{so2}{y}$ (1)	$\log \frac{nmvoc}{y}$ (2)	$\log \frac{pm25f}{y}$ (3)	$\log \frac{nox}{y}$ (4)	$\log \frac{co}{y}$ (5)
logypc	-0.82*** (0.02)	-0.80*** (0.01)	-0.78*** (0.02)	-0.75*** (0.01)	-0.92*** (0.01)
Observations	6,235	6,235	6,235	6,235	6,235
R ²	0.24	0.55	0.29	0.43	0.49
Adjusted R ²	0.21	0.53	0.27	0.42	0.48
<i>Note:</i>			*p<0.1; **p<0.05; ***p<0.01		

TABLE 3. Regressions for pm10, bc, oc, pm25b & nh3

	$\log \frac{pm10}{y}$ (1)	$\log \frac{bc}{y}$ (2)	$\log \frac{oc}{y}$ (3)	$\log \frac{pm25b}{y}$ (4)	$\log \frac{nh3}{y}$ (5)
logypc	-0.88*** (0.01)	-0.88*** (0.01)	-0.85*** (0.01)	-0.94*** (0.02)	-0.98*** (0.01)
Observations	6,235	6,235	6,235	6,229	6,235
R ²	0.51	0.50	0.45	0.39	0.66
Adjusted R ²	0.50	0.48	0.44	0.37	0.65
<i>Note:</i>			*p<0.1; **p<0.05; ***p<0.01		

From the analysis above, we can divide our pollutants into a category that is closely related to industrial production and a category that is related to non-industrial production. The former includes so2, nmvoc, pm25f, nox and co. The latter includes bc, oc, pm25b and nh3. pm10 measures a large range of industrial and non-industrial pollutants.

2.2. Regressions with Trade Variables. Using fixed effects, the paper examines the impact of **emission intensity** (total emissions divided by real GDP per-capita) of these pollutants on **real GDP per-capita** and **trade variables**. The fixed effects regression allows us to estimate β , the elasticity of the emission intensity of pollutants with respect to per-capita income.

A economy can be divided into traded and non-traded sector. The traded sectors are ones that export or import goods and services. The non-traded sectors' output is either consumed or invested in the domestic economy. Traded sector is exposed to the prices in the international markets and any change in these prices have an immediate impact on the traded sector. Conversely, non-traded sector is insulated from changes in the international prices. Our interest lies in understanding if change in international trade played a role in improving or worsening the environment in countries across the world.

- φ_{it}^x and φ_{it}^m are the shares of export and import sectors in the economy. p_{it}^x , p_{it}^m and p_{it}^{da} are the price levels in the export, import and non-traded sector.
- $\tau_{it} = \frac{p_{it}^x}{p_{it}^m}$ is the *terms of trade* which measures the relative price of a country's exports and imports.
- $\chi_{it} = \varphi_{it}^x - \varphi_{it}^m$ is *trade balance* which measures the *export orientation* of the economy.
- $\pi_{it} = \frac{p_{it}^x + p_{it}^m}{2p_{it}^{da}}$ is the *traded and non-trade sector price ratio* which measures the ratio of prices in the traded sectors and non-traded sectors.
- $\zeta_{it} = \varphi_{it}^x + \varphi_{it}^m$ is the *openness* which measures the total share of the traded sector in the economy.
- π and χ measure the price competitiveness and share of the export sector relative to the import sector.
- τ and ξ measures the price competitiveness and share of the traded sector relative to the non-traded sector.

Country i 's population at time t is given by P_{it} and total real output is given by Y_{it} . The total emission from a particular pollutant j is given by E_{it}^j . Country i 's *per-capita output* is

given by $y_{it} = Y_{it}/P_{it}$ and *emission intensity* for pollutant j at time t by $e_{it}^j = E_{it}^j/Y_{it}$. We estimate the following equation:

$$\begin{aligned} \ln e_{it}^j = & \alpha_i^j + \alpha_t^j + \beta_y^j \ln y_{it} + \gamma_\tau^j \tau_{it} + \gamma_\chi^j \chi_{it} + \gamma_\zeta^j \zeta_{it} \\ & + \gamma_{\tau y}^j (\tau_{it} \times \ln y_{it}) + \gamma_{\chi y}^j (\chi_{it} \times \ln y_{it}) + \gamma_{\zeta y}^j (\zeta_{it} \times \ln y_{it}) + \varepsilon_{it} \end{aligned} \quad (2)$$

- where $e_{it}^j = E_{it}^j/y_{it}$ is the **emission intensity** of the pollutant, E is the total emission, Y is the total output, P the country's population,
- $y = Y/p$ the country's real **per-capita income**,
- $\tau = (p_x - p_m)/p_{da}$ is the **terms of trade** (tot),
- $\zeta = \varphi_x + \varphi_m$ is the **openness** measured by the share of the total traded sector in the economy (open) and
- $\chi = \varphi_x - \varphi_m$ is the **trade balance** (tb).

The results from regression (2) are presented in Tables 4 and 5. Coefficients from Tables 2, 3, 4 and 5 are summarised in Figure 3. Figure 3 helps us to compare the coefficients estimates obtained from regression (2) with the baseline regression in (1).

Our main interest lies in examining how adding the trade variables to the regression changes the emission intensity elasticity. If we examine $\Delta\beta_y^j = (\bar{\beta}_y^j - \beta_y^j)$, the difference between the elasticity estimates from regression (1) and regression (2), the pollutants falls in three distinct categories. Adding trade variables to the regression reduces the emission intensity elasticity of so2, nmvoc, p25f and co by the largest margin i.e., $\Delta\beta_y^j \in (-0.36, -0.26)$, by a smaller margin for nox, pm10 and bc, i.e., $\Delta\beta_y^j \in (-0.14, -0.13)$, and the elasticities for oc, pm25b and nh3 remain largely unchanged, i.e., $\Delta\beta_y^j \in (-0.02, 0.04)$.

The following observations follow from Table 4 and 5 summarised in Figure 3.

- For so2, nmvoc, pm25f and co, adding the trade variables makes the emission intensity relatively inelastic with respect to per-capita output and the emission intensity increases with terms of trade and openness and decreases with trade balance.

TABLE 4. Regressions for so2, nmvoc, pm25f, nox & co

	$\log \frac{so2}{y}$	$\log \frac{nmvoc}{y}$	$\log \frac{pm25f}{y}$	$\log \frac{nox}{y}$	$\log \frac{co}{y}$
	(1)	(2)	(3)	(4)	(5)
logypc	−0.46*** (0.04)	−0.52*** (0.02)	−0.52*** (0.03)	−0.61*** (0.02)	−0.66*** (0.03)
tot	2.33*** (0.30)	1.56*** (0.15)	1.82*** (0.25)	0.85*** (0.18)	1.66*** (0.19)
open	1.07*** (0.18)	1.42*** (0.09)	0.66*** (0.15)	0.61*** (0.11)	0.94*** (0.11)
tb	−0.48 (0.41)	−0.45** (0.20)	−0.96*** (0.34)	−0.51** (0.24)	−0.76*** (0.26)
logypc×tot	−0.29*** (0.04)	−0.19*** (0.02)	−0.22*** (0.03)	−0.10*** (0.02)	−0.20*** (0.02)
logypc×open	−0.14*** (0.02)	−0.17*** (0.01)	−0.10*** (0.02)	−0.08*** (0.01)	−0.11*** (0.01)
logypc×tb	0.03 (0.05)	0.04* (0.02)	0.09** (0.04)	0.03 (0.03)	0.07** (0.03)
Observations	6,235	6,235	6,235	6,235	6,235
R ²	0.25	0.58	0.31	0.45	0.51
Adjusted R ²	0.23	0.57	0.29	0.43	0.49

Note:

*p<0.1; **p<0.05; ***p<0.01

- Adding the trade variables changes the relationship between emission intensity and per-capita output for so2, nmvoc, pm25f and co by the largest margin.
- The coefficient on terms of trade, openness and trade balance are relatively large and significant.
- Conversely, adding the trade variables does not change the relationship between emission intensity and per-capita output for oc, pm25b and nh3. With some changes nox, pm10 and bc are in between these two cases.

We find that emission intensity of pollutants that are by products of industrial production are relatively inelastic. $-0.67 < \beta_y^{so2}, \beta_y^{nmvoc}, \beta_y^{pm25f}, \beta_y^{nox}, \beta_y^{co} < -0.54$. Conversely, the emission intensity of pollutants that are by products of non-industrial production are relatively elastic $\beta_y^{oc}, \beta_y^{pm25b}, \beta_y^{nh3} < -0.9$. The the emission intensity of pollutants that by products of a mix of industrial and non-industrial production are somewhere in the middle

TABLE 5. Regressions for pm10, bc, oc, pm25b & nh3

	$\log \frac{pm10}{y}$	$\log \frac{bc}{y}$	$\log \frac{oc}{y}$	$\log \frac{pm25b}{y}$	$\log \frac{nh3}{y}$
	(1)	(2)	(3)	(4)	(5)
logypc	-0.75*** (0.02)	-0.75*** (0.02)	-0.82*** (0.03)	-0.91*** (0.03)	-1.02*** (0.02)
tot	0.80*** (0.18)	0.66*** (0.18)	-0.10 (0.20)	-0.11 (0.25)	-0.35** (0.15)
open	0.50*** (0.11)	0.68*** (0.11)	0.59*** (0.12)	0.70*** (0.15)	0.16* (0.09)
tb	-0.06 (0.24)	-0.26 (0.24)	0.28 (0.26)	0.50 (0.33)	0.31 (0.20)
logypc×tot	-0.10*** (0.02)	-0.08*** (0.02)	0.01 (0.02)	0.01 (0.03)	0.05** (0.02)
logypc×open	-0.07*** (0.01)	-0.09*** (0.01)	-0.08*** (0.01)	-0.09*** (0.02)	-0.02** (0.01)
logypc×tb	0.01 (0.03)	0.02 (0.03)	-0.03 (0.03)	-0.07* (0.04)	-0.06*** (0.02)
Observations	6,235	6,235	6,235	6,229	6,235
R ²	0.52	0.51	0.46	0.39	0.66
Adjusted R ²	0.50	0.49	0.44	0.37	0.65
<i>Note:</i>			*p<0.1; **p<0.05; ***p<0.01		

$-0.9 < \beta_y^{bc}, \beta_y^{pm10} < -0.78$. It is useful to compare the emission intensity elasticities obtained from regressing (1) and (2). As we can see from Figure 3 adding trade variables changes the elasticity estimates for certain variables more than others. The patterns seems to be that adding trade variables makes pollutants related to industrial process more inelastic where as it does not change the elasticity for the rest of the variables.

The value of β s in Table 4 and 5 are the direct impact of per-capita real output on emission elasticities. There is also an indirect impact that runs through the interaction variables.

By comparing the coefficients for β in Tables 2 and 3 with Tables 4 and 5, we see that adding trade variables reduces the emission intensity elasticities of pollutants like so2, nmvoc, pm25f, nox and co that are industrial by-products but it does not change emission intensity elasticities of pollutants like bc, oc, pm25b and nh3 which are not related to industrial

production. pm10 lies in between the two categories since it captures both industrial and non-industrial by products.

To interpret the results of Table 4 and 5, we need to account for both the direct and indirect impact of per-capita real output on the various emission intensities. The direct impact runs through the β s and the indirect impact runs τ, χ, π and ξ . To represent the relationship between emission intensities and per-capita real output we construct an emission intensity index. The emission intensity index is constructed by substituting median values of y, τ, χ, π and ξ in year 2012 along with coefficients from Table 4 and 5 into Equation (2). Thus, a country which has a median y, τ, χ, π and ξ in our dataset is given an emission intensity index of 100 for each pollutant j . Figure 4 plots the emission intensity index against the log of per-capita real output.

The slope of the lines in Figure 4 represent how sharply the emission intensity reacts to changes in per-capita real output.

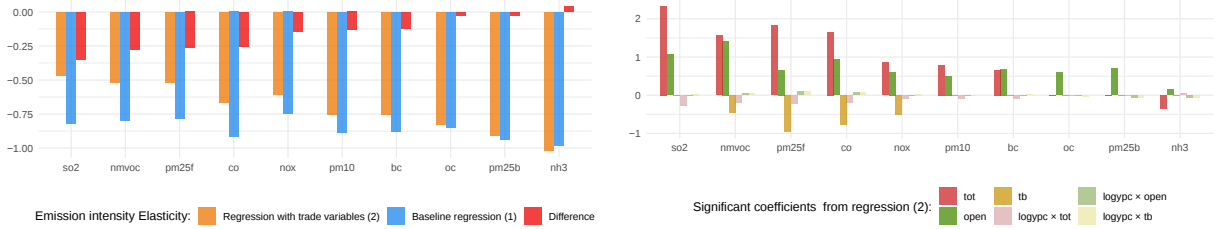


FIGURE 3. Elasticity estimates from regression with and without trade (left) and coefficient estimates from regression with trade variables (right)

2.3. Empirical Results. The elasticity of emission intensity with respect to per-capita output ranges from **-0.46** to **-1.02**. Within this range, there is a distinct pattern.

- We find that for pollutants that are the by-products of industrial production, the emission intensity is relatively **inelastic** with respect to per-capita income, i.e., $\beta_y^{so2}, \beta_y^{nmvoc}, \beta_y^{pm25f}, \beta_y^{nox}, \beta_y^{co}, \beta_y^{bc} \in [-0.75, -0.46]$.

- Conversely, for pollutants that are either by-products of either non-industrial production or a mix of industrial and non-industrial production, the emission intensity is relatively **elastic** with respect to per-capita income, i.e., β^{pm10} , β^{oc} , β^{pm25b} , $\beta^{nh3} \in [-1.02, -0.75]$.

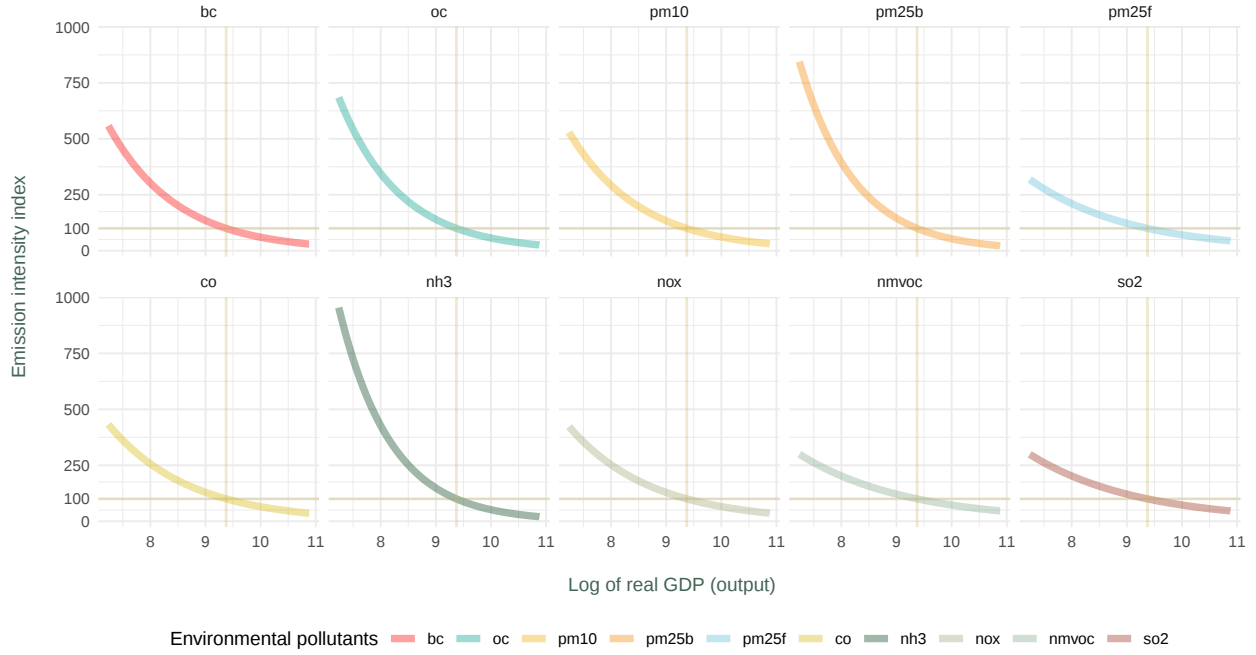
The emission intensity of pollutants are by and large positively related to **terms of trade** and **openness** as measured by the share of the tradable sector in the economy. When both these terms are interacted with the log of per-capita output the coefficient turns out to be negative.

- The emission intensity of pollutants that are the by-products of industrial production (*so2*, *nmvoc*, *pm25f*, *nox*, *co*, *bc*) are more sensitive to the **terms of trade**, an increase in the **share of tradable sector** in the economy and **trade balance** as compared to the pollutants that are either by-products of either non-industrial production or a mix of industrial and non-industrial production, i.e., (*pm10*, *oc*, *pm25b*, *nh3*).

The regressions gives us predicted emission intensity $\hat{e}^j = \hat{e}^j(y, \tau, \chi, \xi)$ for each pollutant j . We transform the emission intensity into an **index** such that the index is 100 each independent variable is at its median level in 2012.²

²Medians values of the independent variables in 2012 are given by $med(y_{i2012}) = 11777.25$, $med(\tau_{i2012}) = 1.09$, $med(\pi_{i2012}) = 1.25$, $med(\chi_{i2012}) = -0.09$ and $med(\xi_{i2012}) = 0.57$. Figure 4 shows us the relationship between this emission intensity index and log of per-capita output. In Figure 4, we can easily observe the cumulative change in the emission intensity due to change in per-capita output.

FIGURE 4. Predicted relationship between the emission intensity index and log of per-capita output where emission intensity for each pollutant is set to 100 for world's median per-capita output in 2012.



Note: Emission intensity for each pollutant is set to 100 for world's median per-capita output in 2012.

3. CONCLUSION

This paper proposes and estimates a pollutant-specific elasticity of emission intensity with respect to income per capita, using a long, run global panel for ten major pollutants. Three results stand out. First, emission intensity falls with development across all pollutants, but the pace differs: industrial pollutants exhibit smaller gains for a given rise in income than pollutants associated with household energy or agriculture. Second, exposure to international trade is associated with higher emission intensity at low income levels but weakens the link between income and intensity as countries get richer, consistent with stronger technique upgrading in more open economies. Third, these patterns are robust across specifications designed for comparability.

The analysis underscores the complex interplay between economic growth, trade, and environmental impact. Emission intensity’s varying elasticity with respect to per-capita income suggests that industrial and non-industrial pollutants respond differently to economic changes. Policymakers must consider these differences when designing strategies to reduce emissions. The positive correlation between emission intensity and trade variables highlights the environmental cost of economic openness, necessitating a balanced approach to trade and environmental policies. By understanding these dynamics, we can better address the environmental challenges posed by economic development and strive for sustainable growth.

These findings carry direct policy implications. Because elasticities differ across pollutants, *uniform* environmental targets risk misallocation. Where elasticities are small in absolute value (e.g., industrial stack emissions), policy will need stronger, technology-forcing instruments—standards, cap-and-trade with tight caps, or targeted fiscal support for abatement and fuel switching—to accelerate decoupling. Where elasticities are larger (e.g., residential or agricultural pollutants), complementary measures that ease adoption—clean cooking transitions, fertiliser management, and transport reforms—can deliver large gains alongside income growth. The trade results suggest that integration with global markets can reinforce technique upgrading once a basic regulatory and institutional capacity is in place, but

may raise intensity at earlier stages through composition effects; transitional safeguards and minimum performance standards can help manage this trade-off.

Two limitations qualify the interpretation. First, although country and time fixed effects absorb many confounders, income and trade are not strictly exogenous. Future work should leverage plausibly exogenous variation—gravity-predicted openness, world price shocks, or trade-policy events—to sharpen identification and to trace composition versus technique more explicitly. Second, ratios can obscure dynamics in numerators and denominators. Reporting results in parallel for emissions, emissions per capita, and emissions per unit of output, as we do in robustness, helps guard against mechanical artefacts and clarifies channels.

Methodologically, the elasticity lens offers a transparent progress metric that can be tracked over time, compared across pollutants, and communicated to policymakers. It can be embedded in national dashboards, sector strategies, and international monitoring, and it lends itself to decomposition by sector, fuel, and regulation once more granular data are available. Substantively, the results point to a practical policy sequencing: early emphasis on composition-sensitive instruments where elasticities are large, coupled with technology-forcing measures in sectors with stubborn elasticities, and a careful use of trade integration to accelerate technique upgrading.

In short, decoupling is not a single pathway but a portfolio of pollutant-specific trajectories. Estimating the elasticity of emission intensity by pollutant clarifies those trajectories and helps align instruments with where they matter most. Continued work to strengthen identification, widen pollutant coverage, and connect elasticities to concrete policy interventions will improve both the science and the practice of environmental management.

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