Subnational Trade Flows and Environmental Outcomes: Empirical Evidence from U.S.

April 18, 2019

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Abstract: This study utilizes the theoretical framework of Antweiler, Copeland, and Taylor (2001) to estimate the impact of subnational trade on the environment in the United States. The empirical estimates of scale and/or technique, composition, and trade elasticities are obtained for each of the air pollutants: sulfur dioxide, particulate matter, nitrogen oxides, carbon monoxide, and carbon dioxide. After controlling for the endogeneity of trade, I find that the net effect of trade on environmental outcomes varies by pollutant, and is only beneficial with respect to sulfur dioxide emissions. This finding suggests that the impact of trade on environment is not homogenous across all air pollutants, contrary to previous empirical evidence.

Keywords: Air pollution, Environment and trade, ACT model

JEL Classifications: Q53, Q56

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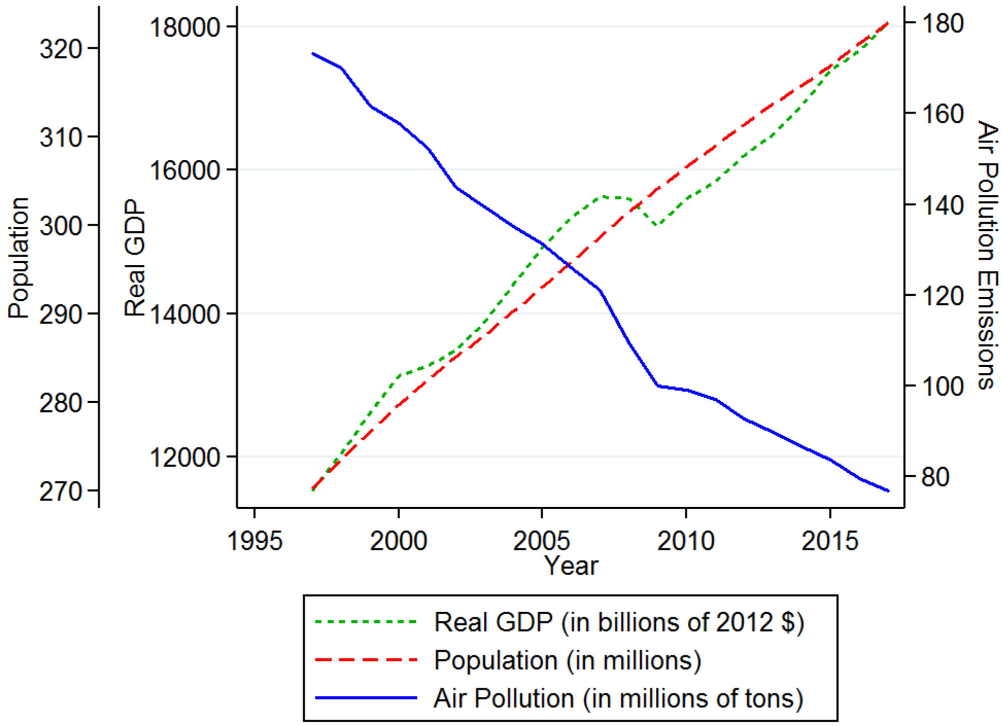
1. Introduction

The air pollution levels in the United States have been declining over the past several decades, despite the fact that the country has continued to grow in terms of the size of the economy and population (see figure 1).

Figure 1: Comparison of Growth Areas and Air Pollution Emissions[1] (1997-2017)



Increased economic activity and development is often associated with the degradation of the environment and the depletion of environmental sinks (Panayotou 1995). However, economic growth and development have also led to advancements in technology that have contributed to cleaner production methods. Consequently, the relationship between environmental quality and different income levels has been widely researched for decades (Panayotou 1995; Stern 2004). More recently, the focus has shifted to trade and its impact on environmental quality. Due to

[1] Air pollution emissions are calculated as an aggregate value of carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds emissions (US EPA 2018). Data on GDP and population retrieved from US Census (2018) and US Bureau of Economic Analysis (2018).

globalization and integration of the world's supply chain networks, trade is increasingly seen as a major contributor to a country's economic growth. Thus, understanding the impact of trade on environmental quality is of great importance to environmental policymakers.

Little attention has been paid to the impact of subnational trade flows and environmental outcomes within the U.S. Due to the size of the U.S. economy, understanding the impact of interstate trade flows is as important as the impact of international trade between countries. To my knowledge, only one paper has attempted to research subnational trade flows and environmental outcomes. Chintrakarn and Millimet (2006) develop a model to assess impact of subnational trade intensity on air, water, land, and underground toxic releases. However, the authors did not utilize the model developed by Antweiler, Copeland, and Taylor (2001) that has become the main approach for analyzing interactions between trade and the environment.

This paper examines the relationship between subnational trade flows and six different air pollutants in the U.S. I apply the theoretical framework of Antweiler, Copeland, and Taylor (2001) to state-level air pollution emissions. In contrast to previous cross-country studies where data have been aggregated at a national level, this paper attempts to harness the heterogeneity that exists among the states. My analysis controls for the endogeneity of trade flows and environmental regulations. I find that the net effect of trade on the air quality varies across pollutants. Additionally, I provide magnitudes of the scale and/or technique and composition elasticities.

2. Literature Review

The question of whether trade is *good* for the environment has generated a large empirical literature. The main approach researchers use to arrive at this effect is to decompose the impact of trade into scale, technique, and composition effects. The scale effect refers to the impact that scalar increases in economic activity have on the environment, holding the structure of the economy and technology constant. Essentially, continued increases in economic activity result in adverse environmental impacts. The technique effect is the emission intensity. Holding all else constant, a decrease in emission intensity will decrease pollution. Decline in emission intensity is closely tied to improvements in the state of technology. Declines in emission intensities happen due to increased productivity and the replacement of older (and dirtier) technologies with newer (and, thus, cleaner) technologies (Stern 2004).

The consideration of both effects—scale and technique—simultaneously led to the development of the environmental Kuznets curve (EKC). Originally, the Kuznets curve was used to refer to the inverted U-shaped relationship between GDP per capita and income inequality (Kuznets 1958). Grossman and Krueger (1991, 1995) found that the same inverted U-shaped relationship exists between economic growth (GDP per capita) and environmental quality and coined the term “environmental Kuznets curve”. They interpreted the shape of the curve as reflecting the relative strength of scale versus technique effects. One example of an interaction of the two effects is as follows: as the standard of living increases, the public will demand a higher environmental quality because environmental quality is a normal good. This, in turn, will create pressure for the government to develop environmental protection policies and regulations that will be aimed at controlling pollution emissions. In this example, the scaling up of the economy is coupled with increased environmental awareness and enforcement of environmental regulations that reduce emission intensity (Stern 2004). Additionally, as GDP per capita raises, industrial economies might experience a structural shift to post-industrial production that focuses more on technology and services and less on production of pollution-intensive goods (Panayotou 1995). If this was not the case, then continual increases in income without a turning point induced by stronger policy response would be detrimental to the environment (Antweiler, Copeland, and

Taylor 2001; Copeland and Taylor 2004). Numerous researchers have attempted to estimate the turning point for different types of pollutants, but the estimates vary greatly (Grossman and Krueger 1991; Panayotou 1995). Nevertheless, the notion that economic growth is simply the means to the environmental improvement has received a fair amount of skepticism (Stern 2004; Tisdell 2001). One of the reasons being that the EKC does not hold for all air pollutants, such as carbon dioxide (Tisdell 2001).

The composition effect refers to the composition (or the cleanliness) of an economy's output, holding constant the scale of the economy and emission intensity. Besides the direct composition effect, trade liberalization also results in a trade-induced composition effect (Antweiler, Copeland, and Taylor 2001). Cole and Elliott (2003) argue that pollution-intensive sectors may be subject to opposing sources of comparative advantage. Both the pollution haven hypothesis (PHH) and factor endowment hypothesis predict that trade liberalization will alter the composition of national output in a manner that depends on the nation's comparative advantage (Antweiler, Copeland, and Taylor 2001). Countries with higher per capita incomes are associated with higher capital abundance and more stringent environmental regulations (Antweiler, Copeland, and Taylor 2001). The environmental regulations effect (ERE) (also known as the PHH) in the context of trade implies that the composition effect is determined by the relative stringency of environmental regulations across countries. ERE predicts that countries with lower than average level of environmental regulations become pollution havens, since these countries will experience comparative advantage in pollution-intensive production relative to those countries that are subject to stringent environmental regulations. Consequently, countries with strict regulations specialize in cleaner production and see their pollution levels decline. On the contrary, the capital-labor effect (KLE) (also referred to as the factor endowment hypothesis) predicts that relatively more capital abundant states specialize in pollution-intensive production, since capital-intensive production is often pollution-intensive. However, this relationship is less clear than that between higher incomes and capital abundance (Cole and Elliott 2003). Nevertheless, the KLE implies that countries with higher per capita incomes and more relative capital experience increases in the levels of pollution. The conflicting effects of ERE and KLE with respect to environmental outcomes suggest that trade liberalization should be conditioned on the relative income and capital characteristics (Antweiler, Copeland, and Taylor 2001).

Antweiler, Copeland, and Taylor (2001) developed a comprehensive theoretical framework to study the impact of trade liberalization on the environment. In particular, the ACT model allows to estimate the individual magnitudes of the scale, composition, and technique effects. Using a 1971-1996 sample of 43 developed and developing countries, the authors find that the detrimental effects of the scale and composition effects are offset by the technique effect and, therefore conclude that trade is good for the environment. The ACT three-effect model has become a well-established practice when analyzing the interactions between trade and the environment. Initially, the ACT model was used to investigate bilateral trade and environmental outcomes across countries but researchers have found that it provides valuable information when applied to states. Some of the propositions of the ACT model may not be applicable to state level as states are a more homogeneous sample than countries. For example, it is unlikely that trade openness will lead to injection of clean state-of-art production techniques from one state to another, since the level of production is more or less uniform (Chintrakarn and Millimet 2006; Chintrakarn 2013). Chintrakarn and Millimet (2006) implement a modified ACT model to analyze state-level pollution. They argue that the analysis of U.S. subnational trade and environment helps inform the debate over the link between international trade and the environment.

The complexity of mechanisms through which various economic activities impact environmental quality is undeniable, which proposes many challenges for the empirical researchers who attempt to infer causality. The empirical difficulty with assessing the causal effect of trade on environment is rooted in the fact that environmental quality, trade, and environmental regulations may be jointly determined, causing the model to suffer from simultaneity bias. Antweiler, Copeland, and Taylor (2001) inform that pollution levels and environmental regulations are determined “endogenously, but recursively” and uses a lagged value of per capita income as an exogenous determinant of pollution levels. Most commonly used method to handle the issue of trade endogeneity is to instrument the trade variable by predicting trade flows using a gravity model (Frankel and Rose 2002; Copeland and Taylor 2004; Chintrakarn and Millimet 2006; Managi, Hibiki, and Tsurumi 2009). While some researchers use the cross-sectional analysis to dissect the scale, composition, and technique effects (Frankel and Rose 2002), a panel dataset proves to be more practical because it allows to use two-way fixed effects (Chintrakarn 2013; Managi, Hibiki, and Tsurumi 2009).

Antweiler, Copeland, and Taylor (2001) find that trade is good for the environment. After controlling for endogeneity, Frankel and Rose (2002) find that trade remains to have a beneficial effect on the environment quality. Similarly, Chintrakarn and Millimet (2006) find that trade has a positive effect on the environment but the effect itself is larger than had previously been found. However, the issue is far from settled as the models utilized to analyze environment and trade nexus in the United States have been incomplete and the magnitudes of the three effects relating to air pollution have not yet been obtained.

3. Methodology

3.1. Specifications

I employ a log-log specification[2]:

$$\ln(E_{it}) = \alpha_1 \ln(I_{it}) + \alpha_2 \ln(I_{it})^2 + \alpha_3 \ln(KL_{it}) + \alpha_4 \ln(KL_{it})^2 + \alpha_5 \ln(I_{it}) \ln(KL_{it}) + \alpha_6 \ln(TI_{it}) + \alpha_7 \ln(TI_{it}) \ln(RI_{it}) + \alpha_8 \ln(TI_{it}) \ln(RI_{it})^2 + \alpha_9 \ln(TI_{it}) \ln(RKL_{it}) + \alpha_8 \ln(TI_{it}) \ln(RKL_{it})^2 + \theta_t + \gamma_i + \varepsilon_{it} \quad (1)$$

where *i* indexes the state and *t* denotes the year. The dependent variable *E* is air pollution emissions per capita or per unit of economic activity (intensity). The independent variables are *I* that denotes one-period lagged 3-year moving average of real Gross State Product (GSP) per capita (hereafter referred to as income), *KL* is the capital to labor ratio (capital abundance), *TI* is trade intensity, *RKL* is the relative capital abundance, *RI* is the relative GSP per capita, θ_t is the time effects, γ_i is the unobservable cross section effects, and ε_{it} is an error term.

The specification for this study varies from the ACT model in one important way. In the ACT model, the dependent variable is sulfur dioxide concentrations at city-level and scale effect is captured by the country's Gross Domestic Product divided by the city's land area, which allows the authors to distinguish between scale and technique effects. In a model that contains information on state-wide emissions, it is no longer applicable to use the same measure for the scale effect. Instead, in specifications that have per capita emissions as the dependent variable, the lagged per capita income and income squared variables will capture both—scale and technique—effects in line with literature on the EKC, as previously discussed. To gain further insight on the two effects, pollution emissions are divided by GSP to obtain a measure of economic intensity. Having economic intensity as the dependent variable means that the lagged per capita income terms on the right hand side will capture the technique effects. Therefore, I am able to calculate the individual

[2] The ACT model uses a log-linear specification. I choose to use a log-log specification, similar to Cole and Elliott (2003), Cole (2006), and Chintrakarn (2013) because it provides a better fit when analyzing state-level data on individual air pollutants.

technique, composition, and trade sample-mean elasticities, yet scale elasticity can only be obtained as a combined scale and technique elasticity. Nevertheless, the specification in the ACT model requires to control for city-specific variables and can, therefore, suffer from omitted variable bias, whereas in this specification that is less of a concern.

Environmental outcomes, trade intensity and environmental regulations may be determined simultaneously. The argument is that state attributes such as infrastructure, topography, and other indirect factors affecting transportation costs may affect trade flows, as well as the scale of pollution-generating activity and/or damages for a given level of pollution, and also income (Chintrakarn and Millimet 2006; Frankel and Rose 2002). The two main approaches to control for the contemporaneous determination of the level of pollution and environmental regulations are to (1) use an instrumental variable approach, and (2) use lagged measure of income. To control for the endogeneity of income, previous studies have used a one-period lagged measure of per capita income as an exogenous variable indicating environmental regulations, including in the ACT model (Antweiler, Copeland, and Taylor 2001; Cole and Elliott 2003; Chintrakarn 2013). Therefore, I employ the same approach and create a one-period lagged moving average of GSP per capita as an exogenous measure of per capita income. The endogeneity of trade flows requires an instrumental variable that is highly correlated with trade. A predicted value of shipments that is derived from a gravity model of bilateral trade has proven to be a good instrumental variable (Frankel and Rose 2002; Chintrakarn 2013; Managi, Hibiki, and Tsurumi 2009). Santos Silva and Tenreyro (2006) propose a linear estimation of a gravity model primarily due to the heteroskedasticity of trade data. Furthermore, Henderson and Millimet (2008) find that a PPML estimation in levels is more efficient than a log-log or log-linearized specification in analyzing subnational trade flows, therefore, I follow their estimation methods and the value of shipments is predicted by

$$shipments_{ijt} = \theta_i \theta_j e^{x_{ijt}\beta} u_{ijt} \tag{2}$$

where $shipments_{ijt}$ is shipments from state *i* to state *j* in year *t* (exports of state *i*), θ_i and θ_j are state *i* and *j*, respectively, fixed effects, x_{ijt} is a vector of controls corresponding to trading partners *i* and *j* in year *t*, and u_{ijt} is the error term. The control variables are physical distance, population size, land area, remoteness, contiguous states dummy, and intrastate shipments indicator (home dummy) (Chintrakarn 2013). Remoteness variable warrants further discussion. Following Wolf (2000), remoteness is defined as the GSP-weighted distance between state *i* and all states excluding state *j*:

$$Remoteness_{ij} = \sum_{k=1,k\neq j}^{48} \frac{D_{ik}}{GSP_k} \tag{3}$$

where *k* denotes all other states excluding state *j*. Remoteness is expected to enter with a positive sign. If state *i* is increasingly remote to all other states excluding state *j*, the value of shipments from state *i* to state *j* will increase.

The observed and fitted bilateral shipments from equation (2) are then used to create summations to generate state-level trade intensity and fitted trade intensity measures:

$$trade_{it} = \frac{\sum_{j,i\neq j}(Shipments_{ijt} + Shipments_{jit})}{\sum_j Shipments_{ijt}} \tag{4}$$

where the numerator reflects the sum of interstate *exports* and *imports* and the denominator is the sum of *exports* plus intrastate shipments.

3.2. Data

The U.S. Environmental Protection Agency (EPA) National Emissions Inventory (NEI) supplies comprehensive and detailed estimates of air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emission sources (US EPA 2018). The NEI is released every three years and the base years of NEI do not match up with the interstate shipment data. However, EPA provides an air pollutant emissions trends data that is based on the NEI and these data are considered to be a good representation of the average state-level emissions based on the data available in the triennial NEI and other state and sector-specific pollutant data that EPA obtains for years in between the NEI base years. The latest version of the dataset for years 1990-2017 provides emission trends for Tier 1 categories which distinguish pollutant emission contribution among major source types. EPA compiles data for the most common air pollutants, including carbon monoxide, particulate matter (2.5 μm and 10 μm), nitrogen oxides, and sulfur dioxide, measured in thousands of short tons. Additionally, data on carbon dioxide was retrieved from the U.S. Energy Information Administration (EIA) and is measured in millions of metric tons. These pollutants are a by-product of industrial processes and each pollutant used in this study is summarized in the table 1, including the main non-natural sources of emissions and other characteristics. Sulfur dioxide is the most widely used pollutant type to measure environmental quality of a country (Grossman and Krueger 1991; Panayotou 1995; Antweiler, Copeland, and Taylor 2001; Cole and Elliott 2003; Stern 2004; Managi, Hibiki, and Tsurumi 2009; Levinson 2009). For the purposes of this study, data is aggregated to pollutant and state-level (see Table 2).

The data on interstate and intrastate shipments are obtained from the U.S. Commodity Flow Survey (CFS) collected by U.S. Department of Transportation (DOT). The Commodity Flow Survey is the primary source of national and state-level data on domestic freight shipments by American businesses (US Census 2018). The CFS covers business establishments in the following industries: mining, manufacturing, wholesale trade, and select retail and services. The survey is conducted every five years (in years ending in "2" and "7") and poses the most significant constraint on my dataset. I use data on shipments for 2002, 2007, and 2012. The value of interstate and intrastate shipments is used to create a trade intensity variable. The reported value of shipments is the market value of goods shipped from manufacturing, mining, wholesale, and select retail and service establishments, as well as warehouses and managing offices of multi-unit establishments (US Census 2018).

The data for the other variables are obtained from several sources. Real GSP (in chained 2012 dollars) and private nonfarm labor force are obtained from the U.S. Bureau of Economic Analysis (2018). El-Shagi and Yamarik (2018) supplies the data on real state-level capital data (in 2009 dollars). The estimates for the level of capital are based on the sectoral composition of states. The capital data is divided by the private nonfarm labor force to obtain the physical capital stock per worker that is used to measure capital abundance. The population and land area measures are retrieved from the U.S. Census (2018).

The final dataset has a sample size of 144. The dataset contains observations on 48 states over three years (2002, 2007, 2012). Alaska, District of Columbia, and Hawaii are omitted from the sample due to missing observations for the pollution and trade variables.

4. Empirical Results

4.1. Gravity Model

The results from the gravity model of bilateral interstate trade flows show that exogenous geographical variables are generally statistically significant determinants of the value of shipments between states (see Table 3 and 4). As expected, greater geographical distance between the origin and destination states enters with a negative sign. The coefficients of the population size for both origin and destination states are positive and statistically significant across all years. Origin remoteness enters with a positive and statistically significant coefficient in all years, as expected, but destination remoteness is statistically insignificant. A possible explanation is that, as an exporter, if the exporting state is increasingly remote to all other states, excluding the state it is exporting to, the more intense will be the trade between the origin and destination states. Since destination state's remoteness is not statistically significant and the sign of coefficients is not consistent across years, I find that the remoteness of the destination state is not of importance. The area of the exporting state, home state dummy, and contiguous states dummies have positive impact on the value of shipments. The high measures of R-squared after controlling for origin and destination state fixed effects show that the geographical variables explain most of the variation in the value of exports.

To further test the strength of the trade intensity's instrument, a two-way fixed effects regression of actual trade intensity on predicted trade intensity shows that the predicted variable explains 40.8 percent of the variation in the actual variable. The coefficient of 0.946 is close to 1, which means that the correlation between the actual and predicted values of trade intensity is strong. This, in turn, indicates that predicted trade intensity is a good instrument.

4.2. Main Results

The determinants of per capita air pollution emissions for each pollutant are summarized in tables 5 and 6. The first two columns for each pollutant are estimated using a two-way fixed effects specification, where the second specification allows for the quadratic terms of per capita income, capital-labor ratio and the interaction of both. The third and fourth columns are organized in the same way and estimated using a GMM method for instrumental variables. The inclusion of quadratic terms is justified by the additional variation that is explained in the dependent variables across all specifications.

The results vary across pollutants and I find mixed evidence with respect to the net effect of trade on the environment. I begin by discussing the composition effect and the respective elasticities. Across all pollutants (except for the second regression for carbon monoxide where the coefficient enters statistically significant), the terms capturing the composition effect, i.e. the capital-labor ratios, are not statistically significant. This finding confirms the proposition that states are a more homogeneous sample than countries and, therefore, factor endowments are not expected to have a direct and significant impact on environmental outcomes (Chintrakarn 2013). According to the ACT model, the capital-labor ratio should enter with a positive sign because capital abundant entities are producing pollution-intensive goods and, therefore, the pollution levels will be higher, but, even though some specifications have the positive sign on the capital abundance, this effect is largely insignificant. Furthermore, CO_2 is the only pollutant that seems to respond to increases in capital abundance.

In the per capita emissions regressions, the per capita income terms capture scale and technique effects. In specifications that allows for squared terms of per capita income, I find that per capita pollution levels are declining at an increasing rate for all pollutants, albeit this effect is statistically significant only for CO and NO_X. This finding partially supports the EKC, but also provides evidence that the EKC does not hold for all air pollutants. Therefore, I obtain mixed results with respect to the EKC. Looking at the scale and technique elasticities, I find that for the average state within the sample, the scale elasticity dominates the technique elasticity for nitrogen oxides and carbon dioxide. Similar effect is observed for other pollutants, but the scale and technique elasticity is insignificant.

The ACT framework predicts that trade intensity does not have a direct impact on the levels of air pollution. I find that trade has a beneficial effect on both per capita emissions and emissions intensity for SO_2. Similarly, Antweiler, Copeland, and Taylor (2001) find the same significant effect. Increasing trade intensity by 1 percent is associated with a 0.4 to 1.4 percent decrease in PM_{10} per capita emissions for the average state within the sample. Additionally, a 1 percent increase in trade intensity will result in a 0.9 to 2.6 percent decrease in SO_2 per capita emissions for the average state within the sample. Trade intensity elasticity also appears to enter with a negative sign for the rest of the pollutants (except for CO) but the coefficient is statistically insignificant.

The second specification contains air pollution intensity as the dependent variable and allows me to obtain a magnitude for the technique elasticities (see Tables 7 and 8). The majority of findings have remained consistent. Thus, I will focus on the elasticities. I find that technique elasticity is negative and statistically significant for PM_{10} and CO_2 for the average state within the sample. The technique elasticity is also negative for $PM_{2.5}$, SO_2 and CO (two specifications), but unexpectedly positive for NO_X. Though, these effects are not significant.

When trade intensity is conditioned on relative state's income and capital abundance measures, I find that the environmental regulations effect (ERE) is more prominent than the capital-labor effect (KLE) implying that those states that have relatively more stringent environmental regulations specialize in cleaner production. The individual coefficients that correspond to the KLE are not statistically significant for any specification, even though, the coefficient signs are pointing to this hypothesis. Therefore, I estimate trade intensity elasticities for each state to further examine the trade-induced composition effects between states (see Appendix A). A positive slope between trade elasticity and lagged per capita income will point to the KLE for the specific pollutant, but a negative slope will imply that there is the ERE. Therefore, I find evidence of the KLE with respect to NO_X, PM_{10}, SO_2, and CO_2, and evidence of the ERE for CO, and $PM_{2.5}$. These results further affirm that the interactions between trade and pollution outcomes are heterogeneous with respect to the air pollutant used in the analysis.

Furthermore, I find that the net effect of the three elasticities is consistently negative only with respect to SO_2 and conclude that trade is *good* only for the levels of sulfur dioxide.

5. Conclusion

By applying the theoretical framework of Antweiler, Copeland, and Taylor (2001) to the United States, I find that trade has a beneficial impact on the environment only when environmental quality is measured in the emissions of SO_2, which is consistent with previous literature. However, because of the heterogeneity of my results, it shows that various pollutants need to be considered in this type of analysis between trade and the environment.

Additionally, this study finds partial evidence of the environmental Kuznets curve with respect to CO and NO_X. However, since the scale and technique elasticities are positive, this result could point to the fact that environmental regulations and technological advancements are not keeping up with the air pollution emissions for the average state within the sample. Furthermore, I find the opposing effects of the environmental regulation effect (ERE) and capital labor effect (KLE) depending on the type of air pollutant. More research could be done regarding these two effects, as they can be further decomposed into long and short-term composition effects.

This study could be extended and improved in several ways. The same analysis could be applied to land, water, and underground pollution to arrive at a more comprehensive conclusion of the impact of trade on the overall environmental quality. Additionally, while a lagged value of per capita income is considered to have an exogenous effect on the environmental quality (Antweiler, Copeland, and Taylor 2001; Cole and Elliott 2003; Chintrakarn 2013), some researchers argue that per capita income is endogenous and should be instrumented (Frankel and Rose 2002; Managi, Hibiki, and Tsurumi 2009; Cherniwchan 2017).

Table 1: Air Pollutant Characteristics

	Carbon monoxide	Nitrogen oxides	Particulate matter (10 µm)	Particulate matter (2.5 µm)	Sulfur dioxide	Carbon dioxide
Abbreviation	CO	NO_X	PM_{10}	$PM_{2.5}$	SO_2	CO_2
Resultant Impact						
Local	Yes	Yes	Yes	Yes	Yes	No
Transboundary	Yes	Yes	Yes	Yes	Yes	No
Global	No	No	No	No	No	Yes
Non-natural Emission Sources	On-road and stationary combustion	Vehicles, power plants, combustion in industry	Combustion and industrial processes	Combustion, atmospheric reactions of gaseous pollutants	Combustion in energy and transformation industries	Combustion, cement production, and farmland plowing

Table 2: Summary Statistics

VARIABLES	Observations	Mean	Standard Deviation	Minimum Value	Maximum Value
CO	144	242.0	217.4	7.655	1,209
NO_X	144	138.6	128.6	3.931	878.2
PM_{10}	144	385.7	358.4	7.154	2,417
$PM_{2.5}$	144	80.86	58.71	1.772	379.0
SO_2	144	214.4	255.9	2.699	1,276
CO_2	144	117.0	109.4	5.550	660.3
Lagged 3Yr MA GSP Per Capita (*I*)	144	0.045	0.008	0.029	0.069
Relative GSP Per Capita (*RI*)	144	1.000	0.180	0.676	1.624
Capital-Labor Ratio (*KL*)	144	0.154	0.071	0.098	0.610
Relative Capital-Labor Ratio (*RKL*)	144	1.000	0.459	0.680	4.107
$KL \times I$	144	570.2	404.6	3.951	2,083
Trade Intensity (*TI*)	144	1.229	0.236	0.500	1.698
Predicted Trade Intensity (*TI*)	144	1.302	0.246	0.617	1.793
$TI \times RKL$	144	0.978	0.057	0.885	1.314
Predicted $TI \times RKL$	144	0.999	0.163	0.823	2.232
$TI \times RKL^2$	144	1.011	0.046	0.944	1.470
Predicted $TI \times RKL^2$	144	1.044	0.238	0.966	3.109
$TI \times RI$	144	0.994	0.052	0.862	1.242
Predicted $TI \times RI$	144	0.991	0.066	0.840	1.310
$TI \times RI^2$	144	1.007	0.015	0.985	1.111
Predicted $TI \times RI^2$	144	1.010	0.019	0.991	1.140

Table 3: Gravity Model Summary Statistics

VARIABLES	Observations	Mean	Standard Deviation	Minimum Value	Maximum Value
Shipments	6,270	5,288	31,412	1	1,432,562
Distance	6,270	1,188	734.8	10	3,372
Origin Land Area	6,270	0.062	0.047	0.001	0.262
Origin Population	6,270	6.488	6.831	0.500	38.06
Destination Population	6,270	6.536	6.813	0.500	38.06
Origin Remoteness	6,270	335.4	147.5	93.19	774.0
Destination Remoteness	6,270	335.5	145.9	90.24	781.0
Border Dummy	6,270	0.101	0.301	0	1
Home Dummy	6,270	0.023	0.150	0	1

Table 4: Gravity Models

VARIABLES	2002	2007	2012
Distance (log)	-0.996***	-0.967***	-1.005***
	(0.0264)	(0.0301)	(0.0295)
Origin Population (log)	0.768***	0.541***	0.604***
	(0.127)	(0.140)	(0.129)
Destination Population (log)	1.073***	0.868***	0.920***
	(0.164)	(0.170)	(0.190)
Origin Remoteness (log)	1.463*	2.691***	2.529***
	(0.874)	(0.910)	(0.932)
Destination Remoteness (log)	0.0327	-1.270	-0.983
	(0.848)	(0.887)	(0.923)
Origin Area (log)	0.493**	0.774***	0.665***
	(0.194)	(0.206)	(0.211)
Home Dummy	1.059***	1.223***	1.337***
	(0.0909)	(0.100)	(0.0943)
Neighboring States Dummy	0.297***	0.365***	0.452***
	(0.0432)	(0.0468)	(0.0492)
Constant	4.720***	7.126***	6.044***
	(1.357)	(1.459)	(1.569)
Observations	2,039	2,125	2,106
R-squared	0.988	0.989	0.992
Origin Fixed Effects	Yes	Yes	Yes
Destination Fixed Effects	Yes	Yes	Yes

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

Table 5: Determinants of Air Pollution Per Capita Emissions

	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
VARIABLES	Carbon Monoxide (CO)				Nitrogen Oxide (NO_X)				Particulate Matter (PM_{10})			
	OLS	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*
Capital-Labor Ratio (*KL*)	-0.628	17.09**	-0.305	8.841	-0.216	3.151	-0.262	16.01	0.264	-2.485	0.314	-9.307
	(0.883)	(7.496)	(0.961)	(34.85)	(0.311)	(2.916)	(0.409)	(40.08)	(0.199)	(2.358)	(0.270)	(22.88)
KL^2		1.329		3.563		0.0947		-2.286		-0.0910		0.239
		(1.886)		(5.473)		(0.912)		(6.943)		(0.576)		(4.024)
Income (*I*)	2.571*	-26.60**	2.228	-40.11	1.543***	-10.13*	1.532**	0.0315	-0.429	-2.859	-1.068*	-1.781
	(1.460)	(12.64)	(1.956)	(29.96)	(0.454)	(5.140)	(0.648)	(33.56)	(0.341)	(5.395)	(0.563)	(20.11)
I^2		-5.904**		-6.834**		-2.168**		-2.358		-0.178		0.822
		(2.350)		(3.435)		(0.891)		(2.410)		(0.949)		(1.619)
$KL \times I$		4.310**		-0.718		0.991		7.668		-0.791		-3.369
		(1.900)		(15.54)		(0.814)		(20.19)		(0.576)		(11.50)
Trade Intensity (*TI*)	0.0390	0.409	0.978	2.622	-0.367	-0.308	-0.456	-1.476	-0.235	-0.273	-1.191*	-0.893
	(0.566)	(0.562)	(1.293)	(2.534)	(0.277)	(0.317)	(0.581)	(2.810)	(0.211)	(0.213)	(0.715)	(1.675)
$TI \times RKL$	2.641	6.586	-0.139	10.30	-1.113	-0.586	-0.503	-3.772	-0.390	-0.912	-1.102	-1.810
	(2.836)	(4.390)	(4.328)	(11.20)	(1.046)	(1.991)	(2.049)	(7.983)	(0.870)	(1.339)	(1.434)	(5.032)
$TI \times RKL^2$	-1.909	-3.347	-1.176	-11.98	0.0627	-0.207	-2.197	11.36	-0.264	-0.351	0.180	-4.440
	(2.001)	(3.150)	(4.042)	(25.00)	(0.725)	(1.402)	(3.691)	(30.35)	(0.562)	(0.889)	(1.185)	(17.41)
$TI \times RI$	-5.911***	-6.428***	-2.794	-15.89	1.708	1.505	0.624	9.063	2.835**	2.579*	6.206**	3.631
	(1.924)	(2.302)	(6.471)	(19.31)	(1.371)	(1.502)	(2.722)	(23.84)	(1.343)	(1.474)	(2.769)	(14.07)
$TI \times RI^2$	6.388	6.916*	2.968	19.00	-1.060	-0.169	-0.457	-12.88	-4.831*	-3.559	-6.974*	-1.208
	(3.998)	(4.055)	(7.453)	(32.91)	(3.175)	(3.483)	(4.298)	(44.66)	(2.620)	(2.931)	(4.155)	(25.90)
Estimated Elasticity												
Scale & Technique	1.467	0.702	1.706	0.869	1.857***	1.746***	1.647***	1.693	0.11	0.257	0.092	0.235
	(1.529)	(1.33)	(1.675)	(1.584)	(0.439)	(0.497)	(0.492)	(1.033)	(0.295)	(0.373)	(0.462)	(0.716)
Composition	-0.117	-0.192	-0.309	-0.541	-0.418	-0.402	-0.313	0.022	0.198	0.373	0.111	0.022
	(0.775)	(0.8)	(0.863)	(1.276)	(0.314)	(0.398)	(0.356)	(1.095)	(0.19)	(0.242)	(0.288)	(0.645)
Trade	0.05	0.14	1.03	2.034	-0.365	-0.322	-0.619	-0.969	-0.426**	-0.402**	-1.43*	-1.227
	(0.569)	(0.514)	(1.497)	(2.135)	(0.256)	(0.261)	(0.547)	(2.045)	(0.204)	(0.202)	(0.743)	(1.229)
Observations	144	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.305	0.373			0.783	0.789			0.506	0.519		
Number of states	48	48	48	48	48	48	48	48	48	48	48	48
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; standard errors for elasticities obtained using delta method.

Table 6: Determinants of Air Pollution Per Capita Emissions

VARIABLES	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Particulate Matter ($PM_{2.5}$)				Sulfur Dioxide (SO_2)				Carbon Dioxide (CO_2)			
	OLS	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*
Capital-Labor Ratio (*KL*)	0.250	-0.357	0.361	-21.39	0.541	-1.054	0.264	11.83	0.146	0.208	0.127	6.744
	(0.305)	(2.975)	(0.419)	(60.23)	(0.484)	(3.997)	(0.731)	(34.38)	(0.123)	(0.809)	(0.253)	(18.92)
KL^2		-0.424		2.526		-1.303		-3.329		-0.256		-1.576
		(0.919)		(10.20)		(1.243)		(6.010)		(0.277)		(3.207)
Income (*I*)	0.0498	-7.637	-0.290	-21.24	0.136	-15.40	-0.174	-1.780	0.338**	-1.594	0.313	4.327
	(0.521)	(6.666)	(0.748)	(48.63)	(0.708)	(9.937)	(1.380)	(31.80)	(0.158)	(2.108)	(0.319)	(15.58)
I^2		-1.329		-0.784		-2.795		-2.237		-0.400		-0.374
		(1.152)		(3.082)		(1.935)		(3.181)		(0.370)		(1.171)
$KL \times I$		0.264		-9.674		0.894		7.235		0.297		3.789
		(0.973)		(30.29)		(1.784)		(16.91)		(0.332)		(9.497)
Trade Intensity (*TI*)	-0.331	-0.376	-0.726	0.899	-1.112***	-1.254***	-2.309**	-3.537	0.0181	-0.00667	0.184	-0.510
	(0.282)	(0.332)	(0.591)	(4.020)	(0.396)	(0.422)	(1.102)	(2.778)	(0.0996)	(0.0856)	(0.288)	(1.292)
$TI \times RKL$	-0.0978	-0.731	-1.380	2.085	-1.070	-2.924	1.569	-4.830	0.355	0.0521	0.794	-2.157
	(1.318)	(2.196)	(2.115)	(10.73)	(1.622)	(2.520)	(3.312)	(9.207)	(0.448)	(0.573)	(1.262)	(3.606)
$TI \times RKL^2$	-0.100	0.120	2.413	-15.75	-0.0700	0.833	-4.398	10.58	-0.229	-0.00587	-2.036	5.863
	(0.884)	(1.577)	(3.289)	(45.08)	(1.068)	(1.763)	(5.772)	(26.35)	(0.300)	(0.400)	(2.570)	(14.28)
$TI \times RI$	0.617	0.600	3.511	-9.970	3.718**	3.981*	3.192	13.18	0.384	0.508	0.139	5.812
	(1.242)	(1.641)	(2.775)	(35.45)	(1.816)	(2.061)	(4.848)	(20.80)	(0.362)	(0.324)	(1.353)	(11.08)
$TI \times RI^2$	-1.228	-0.367	-3.284	19.96	5.214	6.399	5.078	-6.805	-1.388*	-1.481	-2.584*	-10.40
	(2.729)	(2.729)	(3.920)	(66.97)	(3.944)	(3.920)	(7.916)	(37.40)	(0.761)	(0.903)	(1.474)	(20.82)
Estimated Elasticity												
Scale & Technique	0.168	0.249	0.362	0.326	0.779	0.975	0.374	0.671	0.416***	0.431***	0.352**	0.484
	(0.504)	(0.554)	(0.541)	(1.408)	(0.648)	(0.633)	(0.979)	(1.172)	(0.142)	(0.143)	(0.151)	(0.456)
Composition	0.234	0.319	0.068	-0.304	0.349	0.625	0.626	1.03	0.215	0.277*	0.307**	0.501
	(0.305)	(0.331)	(0.347)	(1.643)	(0.463)	(0.582)	(0.560)	(1.090)	(0.143)	(0.158)	(0.139)	(0.529)
Trade	-0.381	-0.351	-0.631	0.376	-0.962***	-0.912***	-2.611**	-2.913	-0.065	-0.063	-0.089	-0.369
	(0.234)	(0.241)	(0.572)	(2.918)	(0.349)	(0.346)	(1.143)	(2.156)	(0.094)	(0.091)	(0.228)	(0.951)
Observations	144	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.331	0.346			0.830	0.839			0.789	0.794		
Number of states	48	48	48	48	48	48	48	48	48	48	48	48
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; standard errors for elasticities obtained by delta method.

Table 7: Determinants of Air Pollution Intensity

VARIABLES	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Carbon Monoxide (CO)				Nitrogen Oxides (NO_X)				Particulate Matter (PM_{10})			
	OLS	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*
Capital-Labor Ratio (*KL*)	-0.741	16.63**	-0.453	10.01	-0.329	2.686	-0.410	17.17	0.151	-2.950	0.166	-8.143
	(0.867)	(7.419)	(0.948)	(31.57)	(0.331)	(2.906)	(0.461)	(44.27)	(0.186)	(2.284)	(0.276)	(19.05)
KL^2		1.111		3.116		-0.124		-2.733		-0.309		-0.208
		(1.859)		(4.913)		(0.907)		(7.658)		(0.551)		(3.391)
Income (*I*)	1.627	-27.87**	1.325	-40.16	0.599	-11.40**	0.630	-0.0210	-1.373***	-4.131	-1.970***	-1.834
	(1.451)	(12.51)	(1.921)	(27.42)	(0.466)	(5.064)	(0.679)	(36.95)	(0.327)	(5.455)	(0.590)	(17.39)
I^2		-5.995**		-6.937**		-2.259**		-2.460		-0.269		0.720
		(2.324)		(3.280)		(0.885)		(2.613)		(0.958)		(1.583)
$KL \times I$		4.432**		0.174		1.113		8.560		-0.670		-2.477
		(1.873)		(13.78)		(0.855)		(22.33)		(0.565)		(9.526)
Trade Intensity (*TI*)	0.0720	0.415	1.027	2.492	-0.334	-0.302	-0.406	-1.606	-0.202	-0.267	-1.141	-1.022
	(0.559)	(0.556)	(1.278)	(2.330)	(0.276)	(0.316)	(0.601)	(3.095)	(0.214)	(0.216)	(0.724)	(1.468)
$TI \times RKL$	3.080	6.716	0.687	10.22	-0.674	-0.456	0.323	-3.855	0.0484	-0.782	-0.276	-1.892
	(2.856)	(4.337)	(4.335)	(10.78)	(1.098)	(1.969)	(2.294)	(8.674)	(0.867)	(1.305)	(1.437)	(4.724)
$TI \times RKL^2$	-2.108	-3.337	-1.967	-10.77	-0.136	-0.197	-2.988	12.56	-0.463	-0.341	-0.611	-3.236
	(2.011)	(3.118)	(4.191)	(22.52)	(0.753)	(1.393)	(4.259)	(33.52)	(0.563)	(0.859)	(1.351)	(14.63)
$TI \times RI$	-6.084***	-6.482***	-3.373	-15.02	1.536	1.451	0.0447	9.938	2.663**	2.526*	5.627**	4.506
	(1.924)	(2.302)	(6.400)	(17.36)	(1.424)	(1.532)	(2.888)	(26.32)	(1.319)	(1.459)	(2.801)	(11.92)
$TI \times RI^2$	6.253	6.626	2.815	17.03	-1.196	-0.460	-0.609	-14.85	-4.966*	-3.849	-7.127*	-3.183
	(4.013)	(4.006)	(7.369)	(28.98)	(3.293)	(3.541)	(4.594)	(49.31)	(2.633)	(2.930)	(4.271)	(21.57)
Estimated Elasticity												
Technique	0.493	-0.246	0.7	-0.09	0.883**	0.799	0.641	0.734	-0.864***	-0.691*	-0.914*	-0.724
	(1.514)	(1.322)	(1.648)	(1.532)	(0.445)	(0.499)	(0.497)	(1.112)	(0.281)	(0.364)	(0.472)	(0.665)
Composition	-0.147	-0.174	-0.293	-0.474	-0.448	-0.384	-0.298	0.089	0.168	0.19	0.127	0.089
	(0.768)	(0.799)	(0.855)	(1.205)	(0.319)	(0.398)	(0.361)	(1.201)	(0.181)	(0.233)	(0.288)	(0.561)
Trade	0.044	0.132	0.983	1.925	-0.371	-0.33	-0.665	-1.078	-0.431**	-0.41**	-1.477*	-1.336
	(0.561)	(0.51)	(1.471)	(1.992)	(0.255)	(0.261)	(0.546)	(2.247)	(0.205)	(0.203)	(0.754)	(1.087)
Observations	144	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.332	0.396			0.807	0.813			0.612	0.625		
Number of states	48	48	48	48	48	48	48	48	48	48	48	48
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; standard errors for elasticities obtained by delta method.

Table 8: Determinants of Air Pollution Intensity

	I	II	III	IV	I	II	III	IV	I	II	III	IV
VARIABLES	Particulate Matter ($PM_{2.5}$)				Sulfur Dioxide (SO_2)				Carbon Dioxide (CO_2)			
	OLS	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*	*OLS*	*OLS*	*IV*	*IV*
Capital-Labor Ratio (*KL*)	0.137	-0.822	0.213	-20.23	0.429	-1.519	0.116	13.00	0.0336	-0.258	-0.0205	7.908
	(0.290)	(2.869)	(0.374)	(55.96)	(0.509)	(3.972)	(0.784)	(38.47)	(0.138)	(0.815)	(0.309)	(23.18)
KL^2		-0.643		2.079		-1.521		-3.776		-0.474*		-2.023
		(0.884)		(9.484)		(1.237)		(6.697)		(0.270)		(3.935)
Income (*I*)	-0.894*	-8.909	-1.192*	-21.29	-0.808	-16.67*	-1.077	-1.833	-0.605***	-2.866	-0.589	4.274
	(0.505)	(6.607)	(0.703)	(45.20)	(0.730)	(9.891)	(1.442)	(34.76)	(0.182)	(2.105)	(0.370)	(19.06)
I^2		-1.420		-0.886		-2.886		-2.340		-0.491		-0.477
		(1.143)		(2.866)		(1.928)		(3.331)		(0.370)		(1.395)
$KL \times I$		0.386		-8.782		1.016		8.127		0.418		4.681
		(0.931)		(28.13)		(1.802)		(19.01)		(0.362)		(11.66)
Trade Intensity (*TI*)	-0.298	-0.370	-0.677	0.770	-1.079**	-1.248***	-2.259**	-3.666	0.0512	-0.000668	0.234	-0.639
	(0.279)	(0.329)	(0.579)	(3.740)	(0.404)	(0.426)	(1.133)	(3.039)	(0.101)	(0.0858)	(0.324)	(1.583)
$TI \times RKL$	0.341	-0.601	-0.555	2.003	-0.632	-2.794	2.394	-4.913	0.793	0.182	1.620	-2.240
	(1.330)	(2.146)	(1.915)	(10.05)	(1.677)	(2.514)	(3.558)	(9.855)	(0.500)	(0.562)	(1.523)	(4.361)
$TI \times RKL^2$	-0.299	0.130	1.622	-14.55	-0.269	0.843	-5.189	11.78	-0.428	0.00403	-2.826	7.067
	(0.896)	(1.541)	(2.734)	(41.89)	(1.102)	(1.763)	(6.340)	(29.41)	(0.330)	(0.403)	(3.165)	(17.50)
$TI \times RI$	0.444	0.547	2.932	-9.095	3.546*	3.928*	2.613	14.06	0.211	0.455	-0.440	6.687
	(1.225)	(1.628)	(2.636)	(32.96)	(1.868)	(2.080)	(5.076)	(23.17)	(0.414)	(0.333)	(1.596)	(13.60)
$TI \times RI^2$	-1.363	-0.657	-3.437	17.98	5.078	6.109	4.926	-8.780	-1.523*	-1.771*	-2.736	-12.38
	(2.781)	(2.722)	(4.036)	(62.26)	(4.065)	(3.972)	(8.251)	(41.90)	(0.771)	(0.883)	(1.753)	(25.53)
Estimated Elasticity												
Technique	-0.806*	-0.699	-0.644	-0.633	-0.195	0.028	-0.632	-0.288	-0.559***	-0.517***	-0.654***	-0.475
	(0.487)	(0.544)	(0.525)	(1.319)	(0.669)	(0.637)	(1.007)	(1.237)	(0.156)	(0.140)	(0.154)	(0.541)
Composition	0.204	0.337	0.083	-0.237	0.319	0.643	0.642	1.097	0.185	0.295**	0.323**	0.568
	(0.297)	(0.326)	(0.339)	(1.53)	(0.472)	(0.576)	(0.572)	(1.19)	(0.146)	(0.144)	(0.131)	(0.637)
Trade	-0.386	-0.359	-0.677	0.267	-0.967***	-0.92***	-2.657**	-3.022	-0.070	-0.070	-0.135	-0.478
	(0.228)	(0.236)	(0.572)	(2.713)	(0.355)	(0.35)	(1.165)	(2.337)	(0.095)	(0.089)	(0.240)	(1.158)
Observations	144	144	144	144	144	144	144	144	144	144	144	144
R-squared	0.425	0.443			0.840	0.850			0.846	0.856		
Number of states	48	48	48	48	48	48	48	48	48	48	48	48
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; standard errors for elasticities obtained by delta method.

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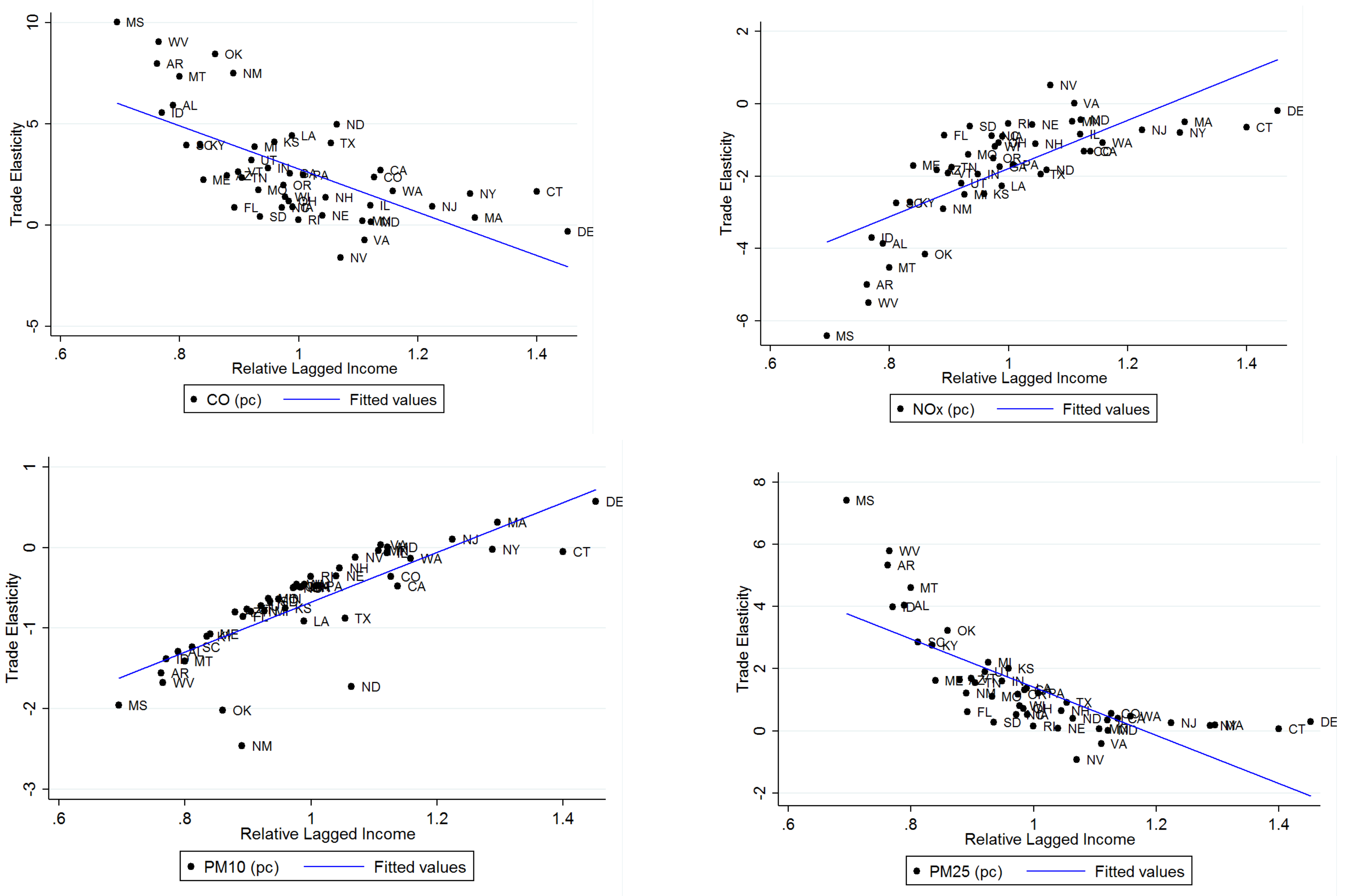
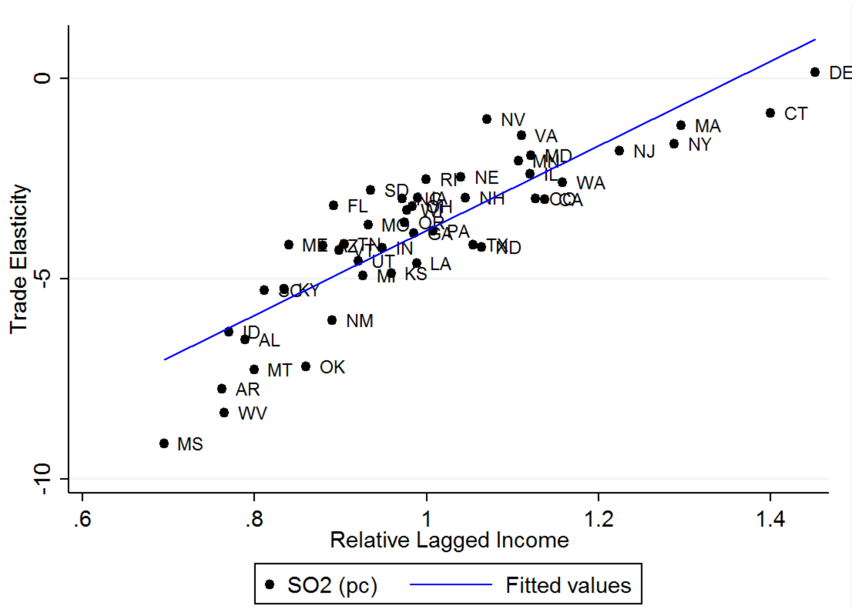
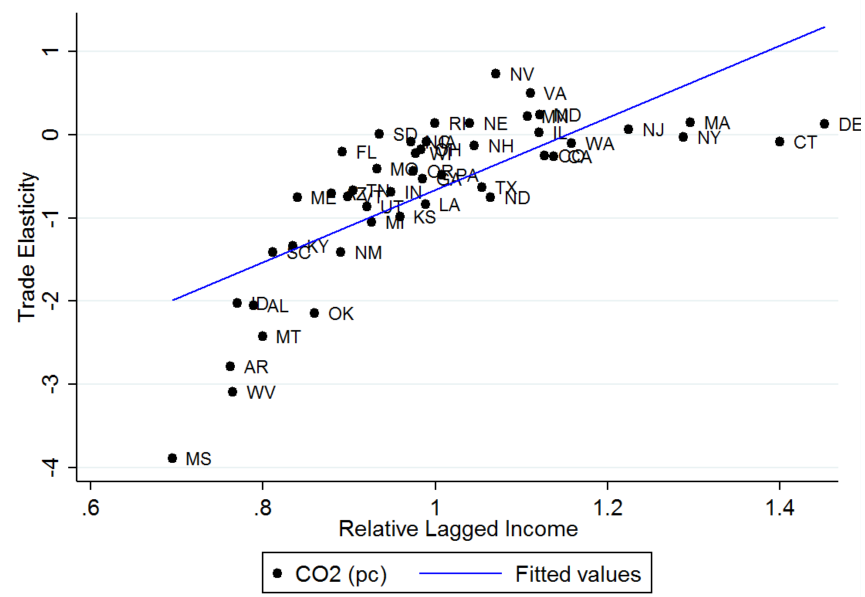
Appendix A: State-Specific Trade Intensities for Each Air Pollutant (Per Capita Measures)




Trade Elasticity
Relative Lagged Income
SO2 (pc)
Fitted values
0
-5
-10
.6
.8
1
1.2
1.4


Trade Elasticity
Relative Lagged Income
CO2 (pc)
Fitted values
1
0
-1
-2
-3
-4
.6
.8
1
1.2
1.4