Ports and Emissions from Shipping

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ABSTRACT

Trade has grown markedly over the last several decades and associated with this growth is an increase in emissions for port traffic. In response to the increases and growing environmental concerns, the Environmental Protection Agency (EPA), the International Maritime Organization (IMO) and individual port authorities have adopted a number of policies designed to abate pollutants emitted from the shipping industry. In this study, I examine the relationship between trade volumes and emissions at a port level, as well as the effects of abatement policies in reducing pollutants. The findings suggest that there is a strong relationship between emissions and trade volumes, and that programs implemented by port authorities do not have a significant impact on air quality.

KEYWORDS: Maritime Ports, Environment, Sulfur, Air Quality, Environment Management System, Traffic, Trade.

JEL CODES: Q5, L9, O2, R4, R5

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1. INTRODUCTION

Over the last five decades, trade has increased dramatically (Blonigen, Wilson 2008). From 1950 to 2004, the annual average growth rate of trade was 5.9% and shows no sign of slowing down (Hummels 2004). Over this same time period, there has been a growing attention to environmental issues. Together with the growth in trade, this awareness has led to a number of different policies designed to reduce the emission from trade in ports. Given the growth in trade, Eyring et al. (2010) estimates the emissions will double between 2010 and 2050. Yet, there has been little research on the effects of trade on emissions and the effects of policy on emissions controlling for trade volumes. In this paper, I develop and estimate a model that links trade volumes to emissions and used a difference in difference model to evaluate the effectiveness of policies.

Historically, there has been a general tendency for institutions to underestimate and ignore the environmental effect of the shipping industry. The Kyoto Protocol, for example, directly requires nations to cut CO_2 emission, but it does not address emissions from shipping in international trade (Endresen et al. 2003). Further, in the U.S., there have been a number of policies introduced by individual port authorities to reduce emissions of their operations. The first port authority to take such initiative was Houston by starting the Environmental Affairs Department in 1980, and developing a policy for environmental compliance. The port was also the first one to be internationally certified for its Environmental Management System.[1] Since then there have been a wide variety of policies introduced at different points in time by different ports.

[1] More information can be found on: http://www.portofhouston.com/inside-the-port-authority/environmental-stewardship/.

As is well known, global warming has become a major issue, and marine vessels cannot be excluded when considering worldwide air pollution. Most vessels used in trade run on cheaper bunker fuels, rather than using propulsion engines that run on cleaner diesel fuels. When consumed, bunker fuels release multiple harmful chemicals into the atmosphere such as nitrogen and sulfur oxides (Corbett et al. 2007) with 70% of these emissions occurring 400km or less from the coast (Eyring et al. 2010). Given the proximity to the coasts at which these chemicals are released, there are concerns regarding air pollution and deteriorating of air quality inland, especially within coastal communities. In addition to environmental problems, there are several impacts on human health such: cardiopulmonary diseases and lung cancer caused by shipping related emissions could lead in fact to 104 thousand annual premature deaths (Eyring et al. 2010).

The predominant chemicals released are nitrogen oxides (NO_x), Sulfur Dioxide (SO_2), carbon dioxide (CO_2), volatile organic compounds (VOC), carbon monoxide (CO), black carbon (BC), and particulate organic matter (POM) (Eyring et al. 2010). Heavy bunker fuels are thick in sulfur, causing great quantities to be released in the atmosphere when these are burned. Sulfur released from marine vessels constitute 5%-8% of the global emissions (Corbett et al. 2007), while ship nitrogen emissions in 1999 represented more than 15% of global nitrogen emissions from fossil fuels (Eyring et al. 2005).

As the concern for the environmental impact of trade continues to grow, there have been many studies trying to estimate the influence of the shipping industry on the global air quality and emissions. Generally, these studies evaluate bunker consumption statistics, assuming that all engines consume fuel in standard conditions and that average consumption measures are a good representation of the overall depletion (Corbett, Koehler 2003). The goal of this research is to provide policy-makers with the most detailed statistics on the effectiveness and the impact of the policies in place. When assessing emission levels, most of the literature focuses on the reliability of bunker sales statistics. In particular, the bulk of literature focuses on whether engine consumption well represents the vessels' aggregate emissions, and if geographical emission representations depict the whole world fleet appropriately (Dalsoren et al. 2009). These issues derive from the fact that the sources for fuel consumption statistics derive from international fuel marine statistics, which some hold are not accurately reported or described consistently by agencies (Olivier, Peters 1999).

Over the last few decades, there has been a developing interest of policy-makers to reduce air pollution from shipping. This has occurred internationally, nationally, and locally. Considering the importance of the growing issue related to shipping issues, the International Maritime Organization (IMO) and Environmental Protection Agency (EPA) have introduced policies aimed at reducing pollution from commercial shipping. The IMO, stressing the importance on sulfur and nitrogen reductions, in 2010, designated regulations off the coast of the U.S. to limit the presence of these pollutants in the fuels used by ships. Focusing on the same issue, the EPA also established sulfur caps on marine fuels at 500 ppm and becoming effective in 2007,

However, before the intervention of the IMO, ports authorities had already been acting to reduce their ecological footprints. Many port authorities started Environmental Management Systems (EMS), in order to achieve ISO14001 certification, to reduce emissions and waste as well as to improve efficiency and overall productivity (Melnyk, Sroufe, Calantone 2003). These policies consist of specializing, monitoring and reporting environmental performance (Sroufe 2003) are all based on each port's characteristics. Primarily based on the ISO 14001 framework, these EMSs are built off 13 elements[2] that go from defining the scope of the EMS and assigning responsibilities, to controlling and managing operations.[3] Analyzing specific plans helps exemplifying the types what these policies actually entail. The program started by the Houston Port Authority, for example, consists of: tenants constantly assessing compliance with regulations, including records and documents reviews, environment education program for all port employees, and incorporating best management practices with every business decision. Together with these initiative, the program also commits the port authority to meeting or exceeding all environmental local, state, and federal regulations.[4] Another example of EMS is the one implemented in by the Massachusetts Port Authority in the port of Boston. This plan includes "green" lease terms for tenants (terms to keep adequately low emissions, such as obligations to switch to low sulfur fuels, and reduce vessel speed when in port), as well as promoting voluntary environmental initiatives.[5]

In the past years, other researchers have focused their efforts in examining environmental consequences of shipping pollution. For example, Corbett and Koehler (2003), Eyring et al. (2005), and Endresen et al. (2007) determined global emission inventories of tankers, their impact on worldwide pollution, and the consequences of these emissions. Others studied the solutions to

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[2]The 13 elements to an EMS as reported by the American Association of Port Authorities (AAPA) in the "An Environmental Management System (EMS) Primer for Ports: Advancing Port Sustainability" are:
1. Define scope of EMS and assign environmental management systems responsibilities; 2. Create environmental policy statement; 3. Identify relevant legal and other requirements; 4. Identify environmental aspects and significant environmental aspects; 5. Establish objectives, targets, and action plans; 6. Develop operational controls; 7. Develop emergency preparedness and response program; 8. Set up a training program for competence and awareness; 9. Create a communications strategy; 10. Set up documentation for the EMS; 11. Monitor, measure, evaluate, and record performance; 12. Conduct audits and correct problems; and 13. Conduct management review.

[3] NSCEP – EMS Primer for Ports, 2007.

[4] PHA, Environmental Stewardship.

[5]Massachusetts Port Authority Port Sustainability Initiatives.

this issue, describing the most relevant inputs and outputs to control for to achieve a more sustainable port. Gupta et al. (2005), for example, found that heavy duty vehicles are the major source of pollution in port areas. Thus, the best management plan to improve air quality in ports consists in measures to provide better maintenance for vehicles, and regulations to avoid the circulations of trucks without pollution under control certification.

In the remainder of this paper, I first summarize previous literature and describe how the approach taken by this study is different from the others. I then provide a more in-depth background of the issue analyzed by describing emissions, starting from how they are measured, their impact on the environment and population of coastal areas, as well as a description of the different regulations implemented so far to control them. In section 4, I describe the data and present descriptive statistics. In section 5, I present the empirical strategy i.e., the panel difference in difference model that I use to estimate the effects of policies, and in section 6 I present the results. Finally, in section 7 and 8, I use the empirical results to analyze and interpret the outcomes of different policies and outline the various policy implications.

2 LITERATURE REVIEW

There are many different studies on emissions and their relationship with international trade. In this study, I examine the contribution of trade to air pollution in port areas, while measuring the effect of emission reduction policies on port operations. In general, the literature falls into two main categories: one is a very quantitative analysis focusing on the quantity of pollutants emitted, the other instead is policy related, focusing not much on the problem, as on the possible solutions. In this section, I present a review of each category. In addition, as I use a panel difference-in-difference estimator to estimate the model, I provide a brief description of its development, and describe a few areas where it has been used previously.

2.1 Emission Inventories

In the last two decades many researchers focused their efforts on measuring how much the world fleet contributes to global emissions by estimating the impact of trade on air pollution. Given the nature of international shipping, allocating emissions accurately can be challenging, thus, prompting the creation of many different estimation techniques that focus on accurate measurement. The most popular approach to estimate total emissions from shipping is analyzing fuel consumption by using average emission values (Corbett, Koehler 2003). However, this method does not take in consideration the conditions in which it was consumed. From this framwork, studies developed different methods to estimate emission levels. Paxian et al. (2010) use a bottom-up approach, where emissions are estimated based on the number of ships in the world fleet, their attributes (ship type, size, speed, and engine power), and ship emission factors such as power requirements and hours of operation. His findings suggest that ships are responsible for approximately 9.9Tg of sulfur dioxide and 667Tg of carbon dioxide for the year 2006. A similar approach is taken by Corbett and Koehler (2003), who also use a bottom-up approach, but instead of using ship engine sizes based on the weight of the vessel: they adopt engine power statistics and apply vessel activity data to find values for vessel fuel consumption. The conclusion shows annual sulfur dioxide emissions of 6.49Tg and carbon dioxide emissions of 249Tg. Many other studies such as Endresen et al. (2003, 2007), and Eyring et al. (2005) all attempted to model fuel consumption and emission inventories using different approaches. These all show different causing uncertainties and problems for policy-makers and atmospheric scientists suggesting that these estimations are still not completely reliable and require further model specifications and improvements.

2.2 Policy implication Studies

In addition to the studies that document the relationship between marine vessels and emissions, there are also a number of studies that evaluate alternative strategies to reduce emissions. This section summarizes this line of research and their findings with regard to the effects of emissions on the environment and cause of climate change.

Michaelowa et al. (2000) examine the negative impact of emissions on climate change. They describe international policies and state that the IMO was successfully able to set limits on the presence of sulfur dioxide in marine fuels but failed to strictly enforce such standards. They also show that non-intervention would bring, with rising sea levels and storminess due to climate change, significant economic costs to protect ports (about 63$ billion for Japan). The research also finds that significant cuts in emissions could be achieved through improvements in hull and propeller design (10% to 30%), and by using sails (10% to 20%) (Michaelowa et al. 2000). Technological development is another element that will be accounted for when measuring reduction in emissions.

Corbett et al. (2009) focus on the effect on CO_2 of hypothetical vessel speed reduction policies similar to the standards set by the IMO through profit maximizing functions that take in account the opportunity costs of reducing speed. The conclusion proposes speed reduction mandates and fuel taxes to induce container ships to reduce their speed and burn less fuel, hence limiting emissions.

Other studies analyzed the effects of present port operation mandates. Giuliano an O'Brien (2007), for instance, present an outline and evaluation of the results of the California Assembly Bill (AB) 2650 at the ports of Los Angeles and Long Beach, which imposes 250$ penalties for marine terminal operators for every trucks that was idle for more than 30 minutes while waiting to enter the dock. The studies estimate the results by doing a before/after analysis of truck queuing and service transaction. The findings suggest no significant effect in reducing queuing in docks after the appointment system was implemented (Giuliano, O'Brien 2007).

2.3 Measuring Effects of Policies on Emissions

There are a number of studies that attempt to measure the effect of policies on emissions. Most of these examine the effects of policy on emissions, but not many that examine sulfur emission and the relationship to trade and policy. A notable similar study that yielded interesting results analyzing the effects of sulfur dioxide in the atmosphere was done by Winebrake et al. (2008), which is described in some detail.

The Winebrake et al. study analyzes and compares different scenarios where the percentage of sulfur dioxide contained in fuel used by ships have been regulated at different levels. Their study focuses on emissions of PM2.5 because particulate matter emissions from the shipping industry are highly correlated with the presence of SO2 in the fuel and with cardiopulmonary related premature mortalities. The analysis collects geospatial information on the concentration of PM2.5 released globally by vessels and estimates its levels in 2012 scenario with no regulations which is used as the control group. This is compared to other three estimated scenarios where emissions have been regulated with: global sulfur caps required by the IMO at 3.5% in 2012, and 0.5% in 2020, and caps within Emission Control Areas at 1% in 2010 and 0.1% in 2020. The study forecasts future sulfur dioxide emissions with these three scenarios and estimates what the human health impact would be if for each one. Once forecasted the sulfur dioxide emissions with non-intervention and with regulations on shipping, they compare them to each other to find which policy was more effective. The control scenario uses constant growing emissions when fuels have 2.7% sulfur content, the second scenario forecasted has fuel sulfur content limited to 0.5% 200 nautical miles from the coast, the third has 0.1% sulfur dioxide level within 200 nautical miles of coastal areas, and the last scenario has a global limit of 0.5% in sulfur levels. The measures of geospatial intensity of PM2.5 are then applied to concentration-risk functions to determine the health impact on the coastal population.

The findings of show that PM2.5 emissions from ships, when no regulation to control the presence of sulfur dioxide in fuels is applied, globally cause between 83500 and 76700 premature cardiopulmonary deaths. When regulations are implemented to areas 200 nautical miles within the coasts, premature cardiopulmonary diseases were estimated to decrease significantly. The difference between the estimates of the control group (no treatment) and the estimates of the other scenarios allows to understand the effect of each treatment on population health. When sulfur caps are limited to 0.5% within 200 nautical miles from the coast, cardiopulmonary premature illnesses decrease by 33800; when instead caps were set at 0.1%, the amount of illnesses were estimated to decrease by 42500. Similarly, a global sulfur cap decreased annual mortalities by 42500.

In the present study, I conduct a similar analysis. In particular, I compare a group with treatment i.e., a policy is in place, to a control group where there is no treatment i.e., no policy in place. The results allow the statistical measurement of the effect of policies on sulfur emissions and isolate the effect of trade volume on emissions.

2.4 Difference-in-Difference Approach

My econometric analysis is based on a panel regression to estimate the effect of trade volume increase over time on the concentration of sulfur dioxide in the atmosphere detected by the monitors closest to the ports selected. This approach allows controls to be introduced for different policies and regulations on ships and ports that affect the concentration of sulfur dioxide in the port area. These estimators provide a statistical assessment of the treatment effects of port specific emission regulations, and of general nation-wide laws. This is done to isolate the effect of trade volumes form these policies from the coefficient of interest i.e., that of the effects of trade volumes to be estimated without bias.

The difference-in-difference method was first introduced Ashenfelter (1978) to study the effect of training programs on earnings. The basic setting of this approach assumes two different groups of observations, and from two different time periods. Only one of the two groups, in the second period is subject to a treatment, while no units are initially subject to the treatment throughout the first period. In order to estimate the effect of the treatment, the average change in the trend of the unaffected group is subtracted from the average change in the trend of the treated group. This yields an estimate of the effect of the treatment so long as the two groups have parallel trends that continues before and after the introduction of policy. Since its introduction, this approach has been widely used in economic research. For example, Card and Krueger (1993) used the approach to analyze changes in unemployment with raises in minimum wage, while Blundell, Duncan and Meghir (1998) used it to examine responses of the labor supply given a change in taxes.

To my knowledge, this approach has not been used to study the effectiveness of emission regulation policies. Within the literature there is a great range of research that focus on analyzing the impact of international freight transport on global emission of greenhouse gases, and how these emissions impact the world environment. See, for example, Endresen et al. (2003), Cristea et al. (2013), and Chapman (2007). Many of these studies also suggest standards and policies that could be used to reduce pollution produced by the shipping industry. Nevertheless, very few observe the current enforced regulations and whether they have been beneficial. This study analyzes whether the efforts to contain the amount of greenhouse gases emitted have been effective or if further efforts and different strategies have to be applied. In my case, there will be multiple ports implementing different policies in different points in time, while some others won't use any protocols to control emissions. The first group of ports consists of the treated group, the second is the control group. The ports will be selected between the most trafficked ports in the US, which will all present similar trends and allows the assumption of parallel trends.

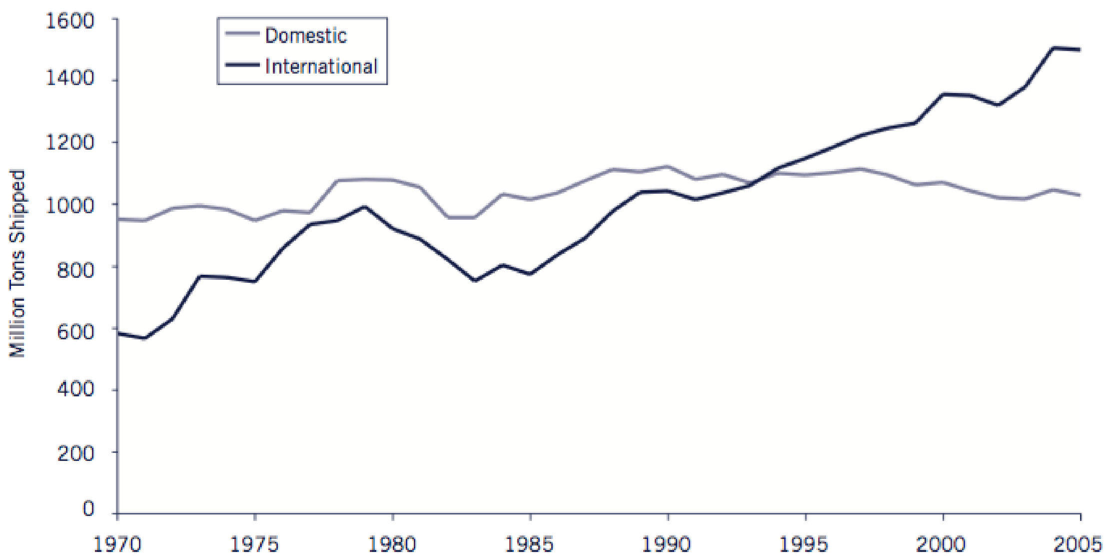
3. BACKGROUND

In this section, I summarize some or the major trends in trade and emission both internationally and locally. I then describe some of the policies that have been introduced to reduce the ecological footprint of maritime shipping. Port cities are often characterized by the presence of heavy pollution due to the proximity of industrial container ships and trucks that burn a great quantity of diesel fuels that release harmful chemicals in the air. The alarming environmental conditions of these areas draw the concerns of many environmental scientists and economists. The topics that mainly concern the researches in this field consist of: the actual amount of the emissions coming from ships and how to measure them, the impact of emissions on climate, and the health related problems caused to the population of port cities. As this study centers on the actual effect of trade growth and the outcomes of environmental policies enforced by port authorities, it is necessary to have knowledge on the procedures, requirements and incentives proposed in the EMSs.

3.1 Growth in Trade and Emissions

World trade has grown at a rate of 5.9% per year with reduced shipping cost coming from technological development (Hummels 2007). To understand the magnitude of this, *Figure 1*[6] shows growth in demand for U.S. domestic and international marine transportation. Naturally, growth in trade hits directly on growth in maritime shipping as it is the most important medium of commerce. For example, in 2001, ships and ports carried 90% of the 5.1 billion tons of goods traded internationally (Steele et al. 2001). The rapid growth of international shipping raised concerns on its environmental impact spurring new laws and regulations. The total world fleet emission inventories are estimated to be 289 metric tons of diesel fuels per year (Corbett, 2003).

Figure 1 - Growth in U.S. Domestic and International Marine Transportation Demand



[6]Source of graphs in Figure 1 and 2: McCollum, David L., Gregory Gould, and David L. Greene. "Greenhouse gas emissions from aviation and marine transportation: Mitigation potential and policies." *Institute of Transportation Studies* (2010). Retrieved May 15, 2016

Also, tanker emissions represent the dominant sources of sulfur depositions, with estimated annual emissions of 236,000 tons (Street et al. 1997). Furthermore, the International Energy Agency (IEA) reports that the shipping industry contributes to 3% of global emissions of greenhouse gasses (GHG) with aviation and marine shipping splitting the share between them. *Figure 2*[6] illustrates this distribution. However, these estimates are very uncertain: IEA top-down estimates are believed to be unreliable and according to bottom-up methods, marine emission of GHG emission could be 50% higher (McCollum, Gould, Greene 2010).

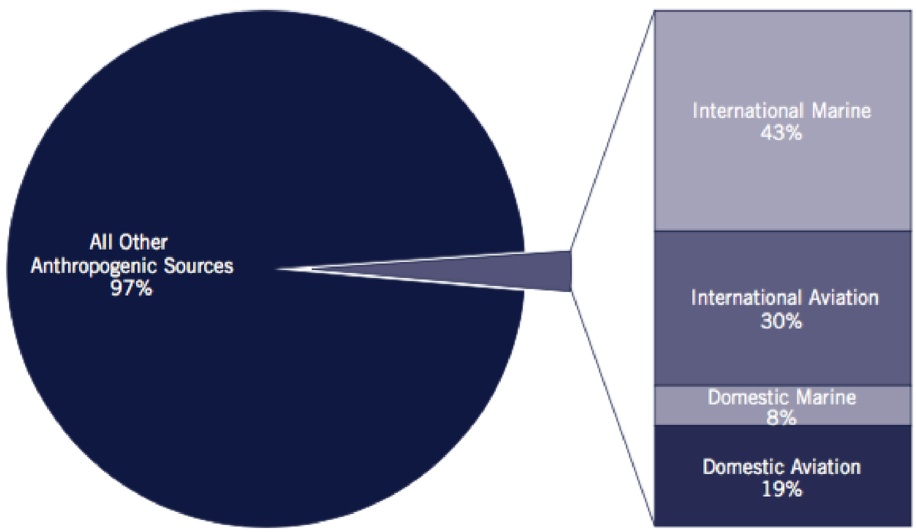


Figure 2 - Global GHG Emissions from Domestic and International Aviation and Marine Transportation in 2005

For the scope of this research, the values of the pollutant used will be the values of the overall presence of chemicals in the atmosphere surrounding the port. The amount of pollution present in the atmosphere of port areas will be represented by the Air Quality Index released by the EPA. These are values measured by monitors all over the country that collect samples of atmospheric air over a period of time and calculate the presence of different pollutants averaged over the time of the given sample. In particular, the chemical used as a reference for the pollution in the atmosphere will be sulfur dioxide as the shipping industry is capable of confronting dominantly to its atmospheric concentration (Capaldo 1999).

3.2 Localized Emissions Impact

Large container ships spend a lot of energy and fuel docking in ports; a lot of emissions are therefore produced close to inland. For example, tanker ship maneuvering represents 10% of SO2 and 6% of NO_X total shipping emissions (Corbett, Fischbeck, 1997). Another form of pollution greatly affecting ports are the emissions caused by unloading and loading containers, which together with maneuvering contribute greatly to the environmental problems happening in coastal cities (Gupta, A. K., S. K. Gupta, Patil 2005). There are also other sources of pollution in ports. These involve port operations using for example heavy duty vehicles and drayage trucks. The emission of sulfates by shipping causes an increase in sulfate in aerosol, and its deposition causes increase in acidity of waters and soil (Doney et al. 2007). Deposition of nitrogen instead encourages the birth of invasive alien organisms by increasing the presence of such chemical in regions whose soils are poor of it, thus harming the ecosystem (Galloway et al., 2003). Ship emissions also have an effect on clouds by generating aerosol, increasing the concentration of Cloud Condensation Nuclei (CCN) to more than 10 times the one of clean air, and changing their reflectivity (Durkee et al. 2000).

As there is a large amount of emissions released in the proximity of coasts, this has a great impact on the inland, especially on port cities, and on the population inhabiting them. The causes of this are in particular the release of ground-level ozone and particulate matter (PM). Studies in this field showed that about 70% of oceans shipping emissions are released 400 km from the coasts, and these are carried further inland by winds (Eyring et al. 2010). The statistics concerning these emissions brings worrying numbers on their direct effect on the health of the populations of coastal residential areas: PM emitted from tanker emissions cause 60,000 cardiopulmonary and lung cancer fatalities every year in the world (Corbett et al. 2007). Other common health impacts caused by PMs are breathing problems such as asthma, and cardiovascular diseases such as heart attacks, all of which can lead to premature mortality (Eyring et al. 2010). The concentration of PM in the air is directly influenced by the amount of sulfur dioxide in the marine fuels used (Winebrake et al. 2009)

3.3 International and Federal Regulations

The legislative and executive organisms that have power to regulate shipping operators in the US are represented by the IMO and the EPA. These agencies have introduced a number of different policies and regulations. The IMO, a UN agency, started regulating the shipping industry in 1973 with the International Convention for the Prevention of Pollution from Ships; this was then revised in 1978 (MARPOL 73/78) (Becker 1997). Countries adhering to this protocol commit to enforce compliance to the MARPOL Annexes through the respective governmental agencies. The US government implemented MARPOL in 1980 during Jimmy Carter's presidential mandate through the Act to Prevent Pollution from Ships (APPS).[7] After that, all the MARPOL requirements applied to U.S. flagged ships, and to non-U.S. flagged ships operating in U.S. waters. MARPOL consisted initially of five Annexes:

- Annex I: regulates the release of oil in waters during operations
- Annex II: regulates the transportation of dangerous liquid substances;
- Annex III: regulates the transportation of dangerous substances as packages;

[7] See: http://www.presidency.ucsb.edu/ws/?pid=45342.

- Annex IV: regulates the prevention of sewage pollution;
- Annex v: regulates the disposal of garbage from ships at ports (Becker, 1997).

Later, in September 1997, MARPOL adopted a sixth annex, which sets global limits on nitrogen and sulfur oxide emissions (by limiting their percentage content in the bunker fuels), volatile organic compounds emissions, and prohibits emissions of ozone depleting chemicals.[8] In the U.S., this entered into force in May 2005, and fully required compliance in 2008 (epa.gov, Regulatory announcement). The legislation applies to all diesel engines with power greater than 130kw (Trozzi 2010). Annex VI was then revised with more stringent limits within 200 nautical miles off the coast on the percentage presence of sulfur dioxide in bunker fuels. In these areas, sulfur and nitrogen oxide caps are set to progressively decrease. These limits started off at a level 1.00% after July 2010, reducing 0.10% after January 2015.[9] These areas are called Emission Control Areas (ECAs). In the U.S., North American ECA were designated by the IMO and the EPA in 2010, entered into force in 2011, and were in effect since 2012.[9]

Regulations to limit the presence of sulfur dioxide in diesel fuels have also been taken independently by the EPA. The U.S. agency in fact did not only set regulations on fuels used by on-road vehicles, but set also set standards non-road diesel engines. These regulations therefore apply to ships and ocean going vessels as well. In May 2004, in fact, the EPA, designated levels of sulfur in marine fuels to decrease by 99% in the Non-Road Diesel Tier 4 Rule.[10] The sulfur reduction in diesel fuels went from 3000ppm to 15ppm when this was fully implemented in 2010.

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[8] More information can be found on: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx.
[9] See: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx.
[10] See https://www3.epa.gov/otaq/marine.htm.

The first step to these fuel improvements moved standards to 500 ppm and entered into effect in 2007; the second stage will reduce it to 15ppm in 2010 for most non-road fuels, and in 2012 for locomotive and marine diesel fuels.[11]

3.4 Port Authorities' Regulations

Most major maritime port authorities in the United States, considering the heavy consequence of non-intervention on the environment of harbor cites, have been setting standards and legislations on their operations. Initiatives by ports to better air quality are always limited to operations within the port as these can commit the port to specific activities but have no legal power over shipping operators (Giuliano, Linder 2013). Many ports in the last two decades started their own Emission Management Systems, based on the framework described by the ISO 14001 standard.[12][13] The EMS plan consists in establishing goals and procedures, as well as monitoring and measuring performance, the ISO 14001 framework allows to increase productivity and reduce waste.[14] These protocols do not only regulate practices, but also initiate recycling activities as well as waste reduction systems for the ports seeking the ISO14000 certification (Sroufe 2003). In the United States, 12 ports took on efforts to regulate emissions, and most of them took the form of EMSs. Analyzing specific plans helps exemplifying the types what these policies actually entail. The program started by the Houston Port Authority, for example, consists of: tenants constantly assessing compliance with regulations, including records and documents reviews, environment

[11] See https://www3.epa.gov/otaq/regs/nonroad/420f08004.pdf.
[12] ISO 14001 is an environmental management standard designed to manage the short and long term ecological impacts of organizations (http://certificationeurope.com/iso-14001-environmental-management-certification).
[13] See: NCESP - Primer for Ports http://www.polb.com/civica/filebank/blobdload.asp?BlobID=10529.
[14] See http://aapa.files.cms-plus.com/PDFs/EMS_onepager.pdf.

education program for all port employees, and incorporating best management practices with every business decision. Together with these initiative, the program also commits the port authority to meeting or exceeding all environmental local, state, and federal regulations.[15] Another example of EMS is the one implemented in by the Massachusetts Port Authority in the port of Boston. This plan includes “green” lease terms for tenants (terms to keep adequately low emissions, such as obligations to switch to low sulfur fuels, and reduce vessel speed when in port), as well as promoting voluntary environmental initiatives.[16]

Other than activity management and coordination procedures, port authorities also attempt to reduce emissions with economic incentives for operators to upgrade to modern systems, use cleaner fuels and waste less. An example of this sort of plan is the one adopted by ports in Southern California (CAAP). The CAAP, Clean Air Action Plan, now represents a model for international and local authorities as this plan was extremely successful. This program, passed in 2006, was planned to target the main emission sources in the ports. These sources include: heavy duty vehicles, ocean going vessels, and cargo handling equipment (Giuliano, Linder 2013). The most ambitious measures of the program were the Clean Truck Program, which involved the upgrade of the entire drayage truck fleet of the port, together with the objective of using shore power to operate ships at berths.[17] This protocol also rewards operators for going beyond compliance of their emission standards. In this way shipping operators are not only encouraged to reduce

[15] See http://www.portofhouston.com/inside-the-port-authority/environmental-stewardship/.
[16] Further information on: http://www.portcompliance.org/pdfs2/MidAtlantic%20Clean%20Ports%20May%2009%20Massport.pdf.
[17] See http://www.cleanairactionplan.org/about-the-plan/.

navigation speed, but also to advance technology in the development of more fuel-efficient engines.[18]

The ports leaders in reducing emissions with these initiatives have been the great ports of the West Coast, where a large amount of pollution comes from their shipping traffic with Asian importers. The Port of Houston, TX, the first port in the U.S. to achieve the ISO14001 certification for their EMS,[19] managed to reduce nitrogen oxide emissions by 3 tons, as well as tackling issues such as storm water impacts and waste cutbacks.[20]

In my model, I examine the relationship between emissions and trade, time, and I develop measures of the various policy regimes as well. The model then allows estimates of both trade and policy on emissions.

4. DATA

The data used consist of a collection of trade totals, air quality statistics, and port coordinates for ports across the United States. The data set for trade totals presents information of the dollar value and weight in pounds of exports and imports per port. The air quality data describes the amount of different pollutants present in the air that was picked up by different sensors across the US, as well as their geographic coordinates. These statistics were drawn from the Army Corps of Engineers (ACE),[21] the Air Quality section of the EPA's website,[22] and the National Geospatial Intelligence Agency (NGA)[23]. The data sets used are accurate and reliable

[18] See https://www.portoflosangeles.org/idx_environment.asp.
[19] See http://www.portofhouston.com/inside-the-port-authority/environmental-stewardship/.
[20] See http://aapa.files.cms-plus.com/PDFs/EMS_onepager.pdf.
[21] See http://www.navigationdatacenter.us .
[22] See http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/download_files.html.
[23] See https://www.nga.mil/About/Pages/Default.aspx.

given the sources they were retrieved from. I addressed and solved any issues that were presented by the data before the analysis.[24]

The dependent variable in the analysis is defined as the percentage quantity of sulfur dioxide in the atmosphere. These Air Quality Index statistics are measured by EPA monitors across the U.S. The annual collection for air quality is made public by the EPA on their website[25]. The data are narrowed down to time period studied and to appropriate geographical location by using longitudinal and latitudinal coordinates. The study measures the influence of trade on air quality in coastal port areas over a time period of 18 years, starting from 1991 to 2009. The data present different observations for each different pollutant measured over different samples of time, and for each air quality monitor. There are many different monitors across the country and these are identified by assigning each one a code for state, county, site number, longitude and latitude.

Sulfur dioxide is measured in "parts per million" (ppm), with a sample duration of 24 hours. This is the main water pollutant responsible for the acidification of the oceans after it settles from the atmosphere. The shipping industry is also the dominant contributor of its emissions (Street et

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[24] Not all pollutants are measured at every point in time, and the data sometimes do not have a pollutant measured at a point in time. The problem coming from having sensors measure different chemical for some years is that the closest measure of a pollutant to a port may vary. This would cause to have a difference in the intensity of the chemical in the air each year because the monitor would be closer or further from the source of pollution, which is the port. The analysis manages to address and solve this problem, by running the model only on the observations weighted by their distance to the port.
Finally, there is also an issue with data collection of policies across ports. Emission reduction policies are not well reported by websites, which lack of clarity in identifying the different programs and what they actually consist of. Furthermore, there is a lot of contradicting information regarding the dates these programs started between different sources. This difficulty in retrieving information raises doubts on the reliability of each source. I addressed this issues by doing some robustness checks by changing the assumptions and variables of the model to analyze the reliability of the estimator. This being said, the most reliable sources resulted being the domains owned by each port authority reporting their environmental initiatives.

[25] See http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/download_files.html.

al., 1997). Each annual observation for sulfur dioxide represents a value averaged over 24 hours, and presents yearly values at different percentiles. The values of the pollutant used are the yearly medians for each sensor, which is "the value from this monitor for which 50 per cent of the rest of the measured values for the year are equal to or less than" (EPA Air Quality Data dictionary). Although there are other chemicals released by tankers in the atmosphere, changes in sulfur dioxide can be considered good indicators of overall changes in emissions in the shipping industry.

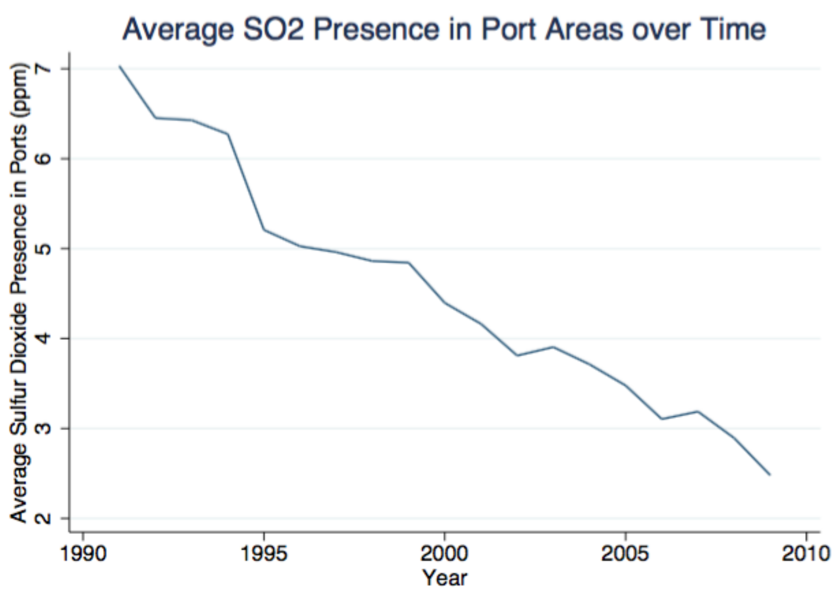
In order to restrict the air quality data to have only relevant information, the observation of the chemicals not related to this study are dropped, together with the ones of the sample durations that are not utilized. Because of the dominant contribution of the shipping industry to its emissions, sulfur dioxide is going to be the only pollutant measured by the estimator. The sample durations chosen for this study are the largest of the samples provided by the EPA, which are 24-hour bulk average for sulfur dioxide. As monitors calculate the presence of a chemical by averaging its count in the atmosphere over a period of time, using the largest sample duration allows to have the more accurate observations in our model. The values of the pollutant observations used are the yearly medians for each sensor.

In order to proceed with the regression model, it is first necessary to match each port with the closest emission and weather stations and merge everything together. To do this, the data set for the geographical coordinates of the ports and the air quality data are initially crossed together. The great circle formula[26] is applied to find the distance between each port and each monitor. This

[26] The Great Circle Formula is a process that allows to find the shortest distance between two points on a spherical surface. This same process can be applied to two different points on planet earth, given their latitudinal and longitudinal coordinates to define their position. This can be done by first multiplying each point's latitude and longitude by π/(180) (these are: lat1, lat2, lon1, lon2); then subtracting the latitude (π/(180)) of one point from the one the other point, and repeating the same for the longitude to obtain the horizontal and vertical distances (these are: dlon and dlat). These variables are then used to generate fa (as: $fa = (sin(dlat/2))^\wedge 2 + cos(lat1) *$

allows to associate each port to each sensor and to calculate the distance between them. The monitors associated to each port are then sorted by distance, the closest to the furthest. Growth in U.S. Domestic and International Marine Transportation DemandIn order to associate one only SO2 indicator to each port, the values detected by each monitor are weighted by their distance to each port using the inverse distance formula[27] and collapsed by year. The port code linked to each port name is included in the data sheet together with the values for the pollutant. The data sheets of each year are appended by port code to have panel data. This results in 18 observations per port, one for each year, from 1991 to 2009. *Figure 3* shows the annual average SO2 presence in ports measured in parts per million and weighted by the distance of the monitor to the port over the time interval of the study.

Figure 3



$cos(lat2) * (sin(dlon/2))^\wedge 2$) and fc (as: $fc = 2 * atan2(sqrt(fa), sqrt(1 - fa))$). Finally, we can calculate the distance by multiplying fc by the radius of the sphere: $distance = R * fc\ (where\ R, Earth's\ radius, is\ 3961\ miles)$.

[27] I generate an emission index for each port by using the inverse distance formula weighting each observation result by its distance from the port. The formula is the following: $\frac{\Sigma\left(\frac{SO2}{Distance}\right)}{\Sigma(\frac{1}{distance})}$.

The graphs represent the distribution of the variable SO2. The graph in *Figure 4* shows that the variable is skewed to the left. It is possible to log the value of the dependent variable to normalize the distribution. A representation of the new distribution is also presented in *Figure 5*. Also, generating the log of the value of the SO2 variable is beneficial for interpretative reasons. It would be in fact difficult to understand the importance of the results if these in parts per million. Thus, allowing results to measure the percentage change would benefit the actual comprehension of the conclusions made by this study.

Figure 4

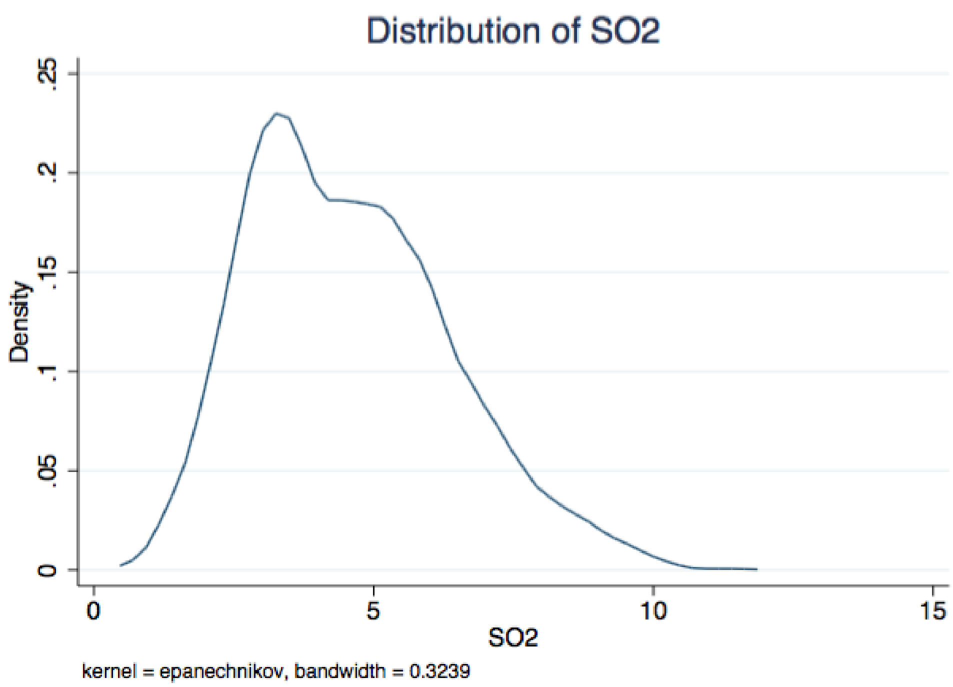
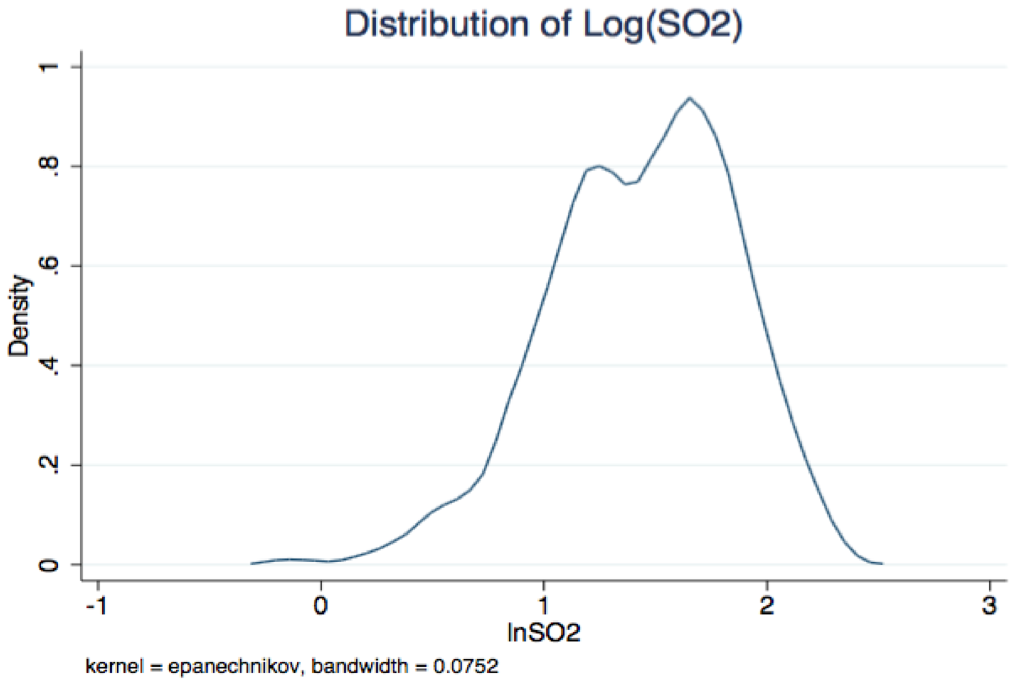


Figure 5



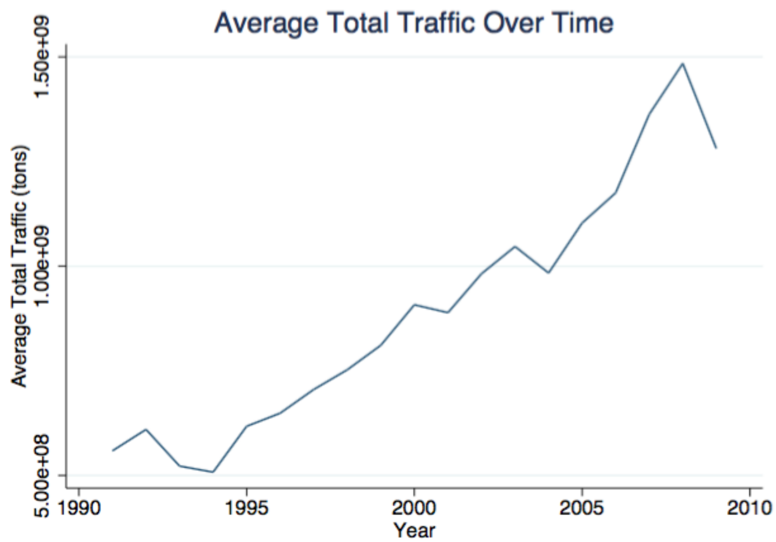
The set of data used for our variable of interest consists of statistics for quantity of goods imported and exported in tons in each commercial port of the United States. The source of these statistics is the ACE, which makes trade data available to the public and are similar to the Census files (Blonigen & Wilson, 2006).[28] The raw data sets contain the data for the total values of goods going through the port in dollars and in tons. These data are supplemented by geospatial information of each port district expressed as longitudinal and latitudinal coordinates, and retrieved from the "World Port Index" offered by the NGA[29]. The data for trade totals go from 1991 to 2009, and the ports analyzed were the top 25 busiest ports in the United States, sorted by total tons of goods traded.

This total value of goods going through the port is measured both in dollars and in tons. For an unbiased investigation I will use the data expressed in physical weight. Measuring trade in

[28] See http://www.navigationdatacenter.us.
[29] See http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015.

currency would create bias problems because, for example, a 1-million-dollar shipment of coal would weigh more than a 1-million-dollar shipment of microchips, which will also take up less space on a ship, allowing to load more goods on the same embarkation. To get a comprehensive value of the goods coming through the port the values for the exports and for the imports of each port are summed in one variable named *TotalTraffic*. *Figure 6* shows the annual average tons of goods that are traded by ports in the United States over the time of the study.

Figure 6



The graph shows the distribution of trade for the 25 busiest ports in the United States. *Figure 7* suggests that the distribution is very heavily skewed to the right. This is driven by a minority of extremely large ports such as the port of New York. These figures are reflected in *Total Traffic* column of Table 1. The data becomes even more skewed when including all the other smaller ports of the whole sample of 192. To adjust the distribution and symmetrize the data, it is possible to log the value of the variable of interest. This improves the fit by changing the scale and making it look more normally distributed. I offer a graphical representation of the new kernel distribution to illustrate this change in *Figure 8*.

Figure 7

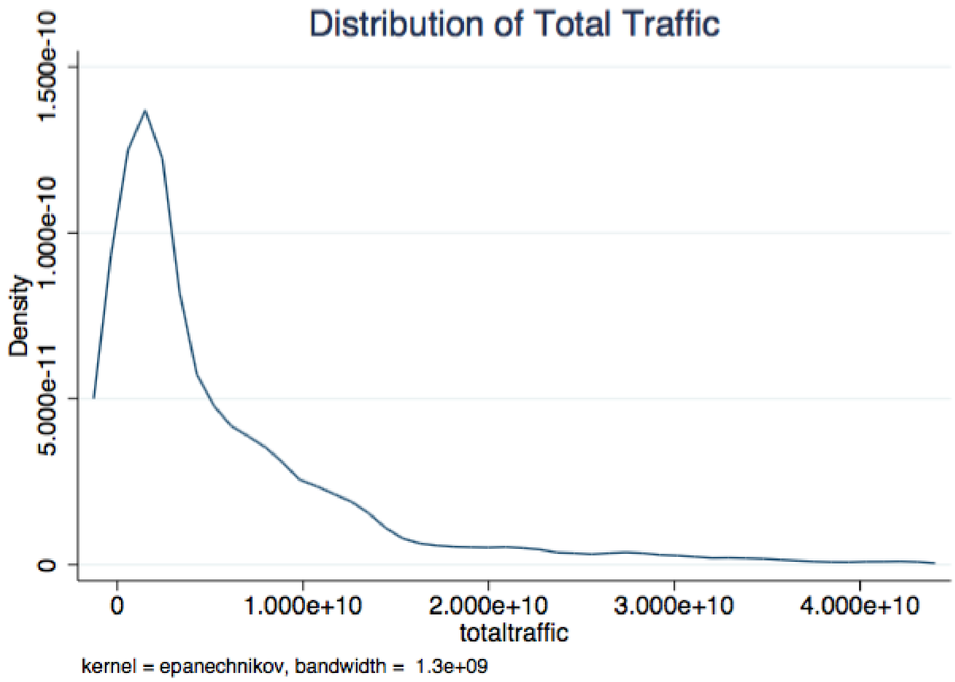
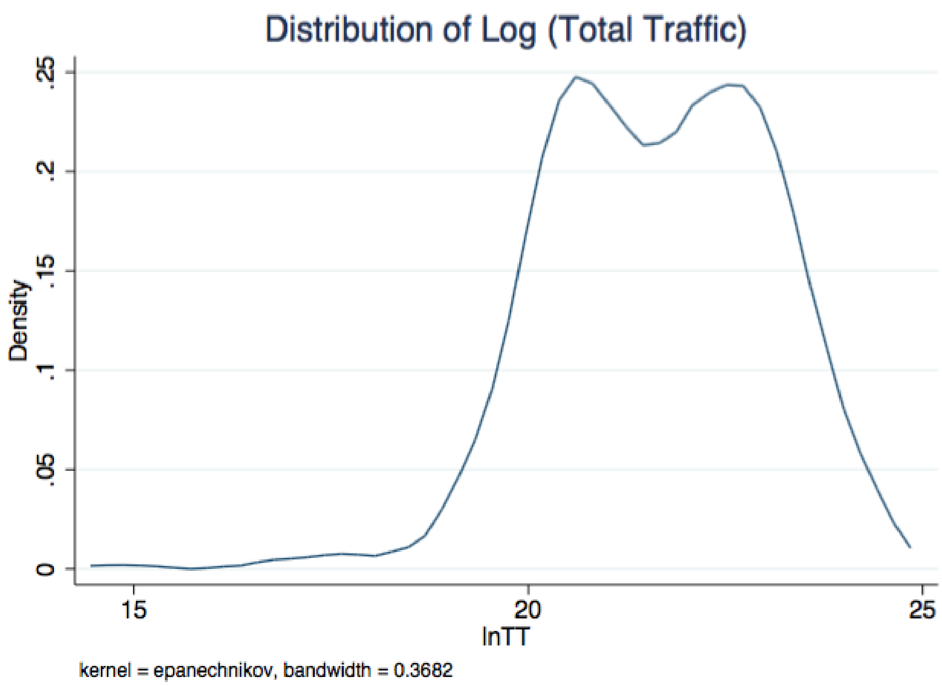


Figure 8



Since the research analyzes the trends over time of sulfur dioxide in the atmosphere surrounding the port, it is necessary to control for port specific emission reduction policies as well as other regulations for world fleet. The model will control for international and local emission reduction regulation that entered into force in the time going from 1991 to 2009. The first five Annexes of MARPOL 73/78 were all implemented before 1991. Annex VI, instead, entered into force in 2005 (epa.gov), allowing us to measure its effect. ECA regulations instead were enforced too late in the US (2010) to need to control for them. Together with Annex VI, I control for the EPA Non-Road Diesel Tier 4 Rule that entered into force in 2008 and decreased sulfur dioxide content in marine fuels by 99%. The data on dates and policy implications were retrieved from governmental and agency websites of the EPA[30] and IMO[31]. The model also controls for regulations on emissions of port operations. Treatment variables for EMSs and similar policies are therefore included in the estimator. The data for the protocols and for the date these were implemented was retrieved from the environmental management section of each ports' website. Using this information, it is possible to measure the treatment effect of each policy on emissions, isolating the effect of an increase in trade volume.

According to "An Environmental Management System Primer for Ports: Advancing Port Sustainability" by the American Association of Port Authorities (AAPA), there is a total of 12 commercial ports in the United States that initiated regulations to reduce waste and pollution produced by port operations, and 9 more that are in the process of developing one. To control for the port specific emission reduction policies affecting the counts of pollution for each facility, a port policy dummy variable created using the difference-in-difference model. The dummy takes the value of zero for all ports. The variable is the assigned the value of 1 at the port where the

[30] See https://www3.epa.gov/otaq/documents/nonroad-diesel/420f04032.pdf.
[31] More information can be found at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx.

policy is implemented, after the year of implementation. The coefficient on this dummy will then represent our treatment effect.

It is also necessary to control for national and international policies that affect all embarkations. It is possible to control for Annex VI of MARPOL 73/78 by creating a dummy variable which takes the value of 1 after the policy is implemented in 2005. Similarly, control for the EPA Non-Road Diesel Tier 4 policy, I create a dummy that takes the value of 1 after 2008. Table 1 describes the 25 busiest ports of entry in the U.S. It shows their names, port codes, and average total traffic in tons of goods imported and exported over the time period analyzed. The table also outlines the names, types, and year of entry into force of policy regulating port operations. The source the policy information was retrieved from is also included. Due to the different dates reported by different agencies, I report the information that was directly included in their official websites. Ports that do not present value for policy "Treatment Year," "EMS," "Other," or "Source" did not have any port specific emission regulations or pollution reduction program for internal operations. Most ports that present a treatment pursued ISO certification of the facilities after implementing an Emission Management System. Seattle and Tacoma started a program called Northwest Ports Clean Air Act, which is the name of a collection of policies aimed to reduce pollution and serves as their own EMS. The ports of Los Angeles and Long Beach instead started the CAAP program in 2006, giving incentives for efforts in cutting emissions to shipping operators.

Table 1 - Top Ports and Policies

Port Name	Port Code	Total Traffic	TreatYear	Policy Name	Source
Boston, MS	401	8.25E+08	2000	EMS	http://www.portcompliance.org/
New York, NY	1001	1.92E+10	2004	EMS	http://www.panynj.gov/about/port-initiatives.html
Philadelphia, PA	1101	1.46E+09	N/A	-	http://www.philaport.com/about/environmental-stewardship/
Chester, PA	1102	5.10E+08	N/A	-	http://www.worldportsource.com/ports/USA_PA_Port_of_Chester_1798.php
Wilmington, DL	1103	9.82E+08	N/A	-	http://www.portofwilmington.com/mainframesets/main_ourport.htm
Baltimore, MD	1303	3.60E+09	2004	EMS	http://www.mpa.maryland.gov/greenport/air.php
Norfolk, VA	1401	7.99E+09	2004	EMS	http://www.portofvirginia.com/stewardship/sustainability/
Newport News, VA	1402	5.09E+08	2004	EMS	http://www.portofvirginia.com/stewardship/sustainability/
Wilmington, NC	1501	7.58E+08	N/A	-	http://www.ncports.com/port-of-wilmington/container-terminal/
Charleston, SC	1601	8.79E+09	N/A	-	http://www.scspa.com/our-impact/
Savannah, GA	1703	8.74E+09	N/A	-	http://www.gaports.com/PortofSavannah.aspx
Jacksonville, FL	1803	1.23E+09	N/A	-	http://www.jaxport.com/community/environmental-awareness
Mobile, AL	1901	4.53E+08	N/A	-	http://www.asdd.com/portfacts.html
Gulfport, MS	1902	1.03E+09	N/A	-	http://portofgulfporteis.com/
New Orleans, LA	2002	2.59E+09	2004	EMS	http://portno.com/Environment
Los Angeles, CA	2704	2.27E+10	2003	EMS	https://www.portoflosangeles.org/environment/ems.asp
Long Beach, CA	2709	2.09E+10	2005	Green Port Policy	http://www.polb.com/environment/green_port_policy/
San Francisco, CA	2809	3.89E+08	N/A	-	http://sfport.com/environmental-programs
Oakland, CA	2811	8.55E+09	2009 (Approved)	-	http://www.portofoakland.com/
Portland, OR	2904	2.06E+09	2000	EMS	http://www.portofportland.com/
Seattle, WA	3001	7.68E+09	2007	EMS	https://www.portseattle.org/Environmental/
Tacoma, WA	3002	5.56E+09	2007	EMS	http://portoftacoma.com/community/
Miami, FL	5201	3.49E+09	N/A	-	http://www.miamidade.gov/portmiami/sustainability.asp
Port Everglades, FL	5203	2.06E+09	2004	EMS	http://www.porteverglades.net/our-community-role/environmental/
Houston, TX	5301	8.05E+09	1980	EMS	http://www.portofhouston.com/about-us/
Long Beach, CA	2709	2.09E+10	2006	CAAP	http://www.polb.com/environment/air/caap.asp
Los Angeles, CA	2704	2.27E+10	2006	CAAP	https://www.portoflosangeles.org/environment/caap.asp

Finally, the concentration of sulfur dioxide in the atmosphere is affected by changes in meteorological patterns. To get an unbiased estimate of the effect of an extra ton of good exported or imported by a port on its air quality, it is essential to include a weather control variable. Wilson et al. (2014) showed through a factor analysis that air temperature had a significant contribution to variations in SO2. The study evaluated also the effect of wing speed and wind direction on levels of other different pollutants, such as CO and NO2, in Malawi. The findings suggest that air temperature has a strong influence on CO, SO2, and NO2 compared to wind speed and wind direction.

Data on yearly temperature summaries was retrieved from the National Climate Data Center (NCDC)[32]. The public data sets of the Annual Climatological Summaries provide average monthly temperature summaries, in tenths of Degrees Celsius, detected by monitors around specific areas in the U.S. By narrowing the data set to the sensor closer to each port and by collapsing the temperature data by each year, it is possible to control for yearly temperature averages of each port. The great circle formula is also used to find the distance between each port and each climate station in order to match the two closest ones. The result is one temperature value for each port for every year.

5 EMPIRICAL STRATEGY

This section outlines the various empirical models I use in the study. I first describe the *Naïve Model* which is a model the variable of interest and no controls. I then progressively add controls to the model in stages. I will add port and time fixed effects, and port specific time trends to the model to yield the most general model. The estimator including all controls is described in

[32] See http://www.ncdc.noaa.gov/data-access/quick-links#An-clim-sum.

the last paragraph. The *Naïve Model* and *Model 1* are not Difference-in-Difference models, while the regression models 2 and 3 are Difference-in-Difference models in order to estimate the effect of policies initiated by individual port authorities. This requires that the groups analyzed, the ports, have parallel trends before the treatment. This assumption is very unlikely to hold across ports of different sizes: in ports of small sizes the change in sulfur dioxide emissions across time will be smaller compared to the biggest industrial ports of the U.S. To examine, I restrict the analysis to ports that have similar characteristics. I Initially I analyze the outcomes yielded on a sample of the 25 ports with the highest levels of imports and exports. After that, I use the same estimators to analyze a sample including all 192 commercial ports of entry in the United States.

Naïve Model

The regression model is based on the principle that, as the value of trade increases, the count of emissions in the atmosphere in the area surrounding the port also increases. This study measures the extent that percentage change in trade has an effect on pollution.

The naïve model in this case is estimates the effect of our variables of interest on the endogenous variable without any controls. The regression model uses the log of the count of sulfur dioxide as the endogenous variable. This is $logSO2_{it}$. The exogenous variable of interest is the log of the amount of goods traded by each port in tons, and is represented by the variable $\log TotalTraffic_{it}$. Furthermore, in the last two decades there has been an increase in awareness of the problem of climate change prompting technological development in ecological sustainability. For example, for ship owners to switching to more energy efficient fleets and port authorities to put in effect eco-friendly practices are processes that occur slowly. Assuming there has been a steady increase in these efforts over time, then this will correspond to a steady decrease in emissions. Therefore, it is possible to use the time variable $Year_{it}$, as a proxy for technological development, with negative effect on pollution. The simple model is described in the equation below. Also, standard errors will be clustered by port to allow them to be correlated over time. This is the same for all the other specifications of the model as it allows for more consistent estimations.

$$logSO2_{it} = \beta_0 + \beta_2 \log TotalTraffic_{it} + \beta_3 Year_{it} + e_{it}$$

Model 1 – Capturing IMO and EPA regulations

I develop further the first model in order to capture the effect of sulfur dioxide emission reduction policies implemented by the IMO (MARPOL Annex VI in 2005) and by the EPA (Non-Road Diesel Tier 4 in 2007). I add a dummy variable that equals to 1 after 2005 ($AnnexVI_{it}$) and another dummy that equals 1 after 2007 ($NRDT4_{it}$) to the specifications of the *Naïve Model*. I also add interaction terms between these dummies and annual trends (these are $AnnexVI$*$\mathrm{Year}_{\mathrm{it}}$ and $NRDT4 * Year_{it}$). By including dummies I am able to analyze the regression discontinuities that occur during these years and how the emission trend changes over time. The effect of these policies are the coefficients on the dummy variable. I also take in consideration the possibility that there may be a response to the policy over time and estimate its effect by summing the coefficient of the dummy variable and the one on its interaction term multiplied by the time trend. Furthermore, I control for port fixed effects ($\sum_i Port_i$). Port fixed effects control for all underlying unmeasurable characteristics of the facilities as well as all those other characteristics of a port that do not change over time which could influence efficiency factors such as ship docking time, and consequently the sulfur dioxide presence. A dummy variable for each port is created to control for this. In this case, the port omitted in the estimator is the port of Houston, this is our base port against which all others are assessed.

$$logSO2_{it} = \beta_0 + \beta_2 \log TotalTraffic_{it} + \beta_3 Year_{it} + \beta_4 AnnexVI_{it} + \beta_5 AnnexVI * Year_{it} + \beta_6 NRDT4_{it} + \beta_7 NRDT4 * Year_{it} + \sum_i \beta_{8i} Port_i + e_{it}$$

Model 2 – Including Weather and Policy Controls

Together with the exogenous values of time and value of goods exchanged from the port, it may also be necessary to control for climate patterns and emission reduction policies. I control for average annual air temperature by including the appropriate variable, in the equation above expressed as AT_{it} (Air Temperature). Controlling for emission reduction policies on port operations done by using the port specific policy dummies generated, $\sum_{it} EMS_{it}$, together with year fixed effect $\sum_t Year_t$. This is where the Difference-in-Difference method is used. The ports unaffected by the treatment serve as a control group to estimate the unbiased effect of the policies on the sulfur dioxide presence by comparing trends between the two groups. Similarly, I control for IMO and EPA regulations by including the year fixed effects. These policies are national and international, thus affecting all ports. To control for these effects, I include a dummy variable for each year. The effect of these regulations will be imbedded in the dummy variables for the years these were implemented. Including year dummy variables picks up variations that happened over time that are shared by all ports and that are not explained by the other explanatory variables. The year dummies need a base group to avoid the dummy variable trap. This will be year 2009, which is omitted from the regression. As I add year dummy variables, I will drop the time trend variable because its effect is embedded in the time fixed effects. Keeping both would cause redundancy in the variables.

$$logSO2_{it} = \beta_0 + \beta_1 logTotalTraffic_{it} + \beta_2 AT_{it} + \sum_t \beta_{3t} Year_t + \sum_i \beta_{4i} Port_i + \sum_{it} \beta_{5it} EMS_{it} + e_{it}$$

Model 3 – Port-Specific Time Trends

I now include port specific time trends to control for the possibility that sulfur dioxide trends in each port were changing at different linear rates over time. This is done by creating a dummy variable for each port and multiplying it with the year time trend variable. This control is represented in the estimator by $\sum_i Port_i * Year_{it}$.

$$SO2_{it} = \beta_0 + \beta_1 TotalTraffic_{it} + \beta_2 AT_{it} + \sum_t \beta_{3t} Year_t + \sum_i \beta_{4i} Port_i + \sum_{it} \beta_{5it} EMS_{it} + \sum_i \beta_6 Port_i * Year_{it} + e_{it}$$

Standard Errors

Finally, in studies that use a difference in difference model, it has become common to cluster the errors over the cross section. In my data, there are 192 ports over 19 years. Clustering by port allows for its errors to be correlated over time and allows for consistent standard errors. Alternative results achieved without clustering standard errors are presented in the *Appendix* sections *A1* and *A2*.

6. RESULTS

In this section, I present the results of the model for the effect on emissions. This discussion is followed by a description of what the outcomes of the estimator described in the previous section imply. The results reported are estimated using two different samples, one restricted to the 25 busiest, and the second unrestricted to all ports of entry in the U.S. All outcomes reported in this section result from estimators which cluster standard errors by port.

25 Port Sample

Table 2 describes the effect of an increase in the percentage volume of trade and of the annual time trend on the percentage presence of sulfur dioxide in port areas. The dependent variable in the model is the log of SO2 measured in parts per million. *Log (Total Traffic)* represents the log of the volume of trade in dollars, while *Year* is the time trend which absorbs the effect of an increase in awareness and technological development. The standard error for each coefficient is reported in parenthesis below the value of the coefficient. The coefficients on the year dummy variable for 2005 and 2007 are also reported. These capture the effects of the policies implemented by the IMO and the EPA which set a cap on the levels of sulfur dioxide in marine fuels. The first column of results called *Naïve Model* shows the outcomes for the regression model with no controls, where the level of SO2 is explained only by trade and year trend. The second column named *Model 1* shows results with the addition of dummies that measure the regression discontinuities caused by IMO and EPA policies previously discussed together with the interaction of the dummies with the time trend variable. *Model 2* controls for air temperature and emission reduction policies carried on by individual port authorities to regulate their operations, together with group and time fixed effects. The third one, *Model 3*, represents the outcomes for the estimator when controlling for port-specific time trends. *Model 3* obtains an unbiased estimate even if the ports do not share the same parallel trend as long as any differences across ports can be captured by a linear trend.

Table 2 – 25 Port Sample

Variables	Naïve model	Model 1	Model 2	Model 3
Log(Total Traffic)	0.0165 (0.0165)	0.0121 (0.0195)	0.0111 (0.0211)	0.0201 (0.0126)
Year – Time Trend	-0.0541*** (0.00231)	-0.0484*** (0.00323)	-	-
Annex VI (2005)	-	140.8*** (41.10)	-	-
Annex VI*Time Trend	-	-0.0703*** (0.0205)	-	-
Non-Road Tier 4 (2007)	-	57.96 (41.65)	-	-
Non-Road Tier 4*Time Trend	-	-0.0288 (0.0208)	-	-
Port Operations policies	-	-	-0.00707 (0.0276)	-0.0437 (0.0410)
Air Temperature	-	-	-0.000209 (0.000335)	-0.000276 (0.000287)
Constant	109.2*** (4.589)	98.28*** (6.370)	1.969*** (0.434)	1.837*** (0.257)
Port Fixed Effects	No	Yes	Yes	Yes
Time Fixed Effects	No	No	Yes	Yes
Port Specific Time Trends	No	No	No	Yes
Observations	475	475	475	475
Number of Ports	25	25	25	25
R2	0.4338	0.9473	0.9525	0.9719

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

The results of the *Naïve Model* show that the Total Traffic variable does not have a significant effect on the sulfur dioxide. This means that a one percent increase in quantity of goods exported or imported in the 25 busiest ports does not significantly affect Sulfur Dioxide. The year effect instead has a significantly negative coefficient, which can be interpret as decreasing the level of SO2 by 5.41% each year. This estimator has an R2 of 0.4338, which means it is explaining 43.38% of the percentage annual variations in the SO2 content in the atmosphere at ports.

IMO and EPA policies affect all ports. In *Model 1* I measure their effect by using an RD model which includes a dummy and an interaction of the dummy with the time trend. The treatment effect is calculated by analyzing the coefficient on the dummy variables. The regression estimations show that the IMO policy had a positive significant effect, while the effect of the EPA policy is not statistically significant. With the assumption that these policies had an effect on sulfur dioxide concentration over time, I add the change in the intercept given by the dummy with its interaction with the time trend multiplied by the value of the time trend. In this case the MARPOL Annex VI developed by the IMO and implemented in the U.S. in 2005 decreases significantly the level of sulfur dioxide in 2005 by 15.15%.[33] Contrarily, the Non-Road Diesel Tier 4 policy did not have a significant impact on sulfur dioxide levels in port areas.[34]

When I include the treatment and air temperature control variables, together with the trend and port fixed effects in *Model 2*, the coefficients of interest do not change significantly. The Traffic of goods at a port still presents a zero effect. The time trend variable is omitted to avoid redundancy with the year fixed effect variable which is already controlling for it. This model uses a Difference-in-Difference specification to estimate the effect of emission regulation on port operations implemented by individual port authorities. The magnitude and direction of the effect is captured by the variable *Port Operation Policies*. The model suggests that these policies do not have a significant effect on the percentile amount of SO2 present in the atmosphere. Similarly,

[33] This figure is calculated from 100*(140.8 + (-0.0703*2005)) = 15.15%
To analyze its significance, I run a T-test testing for the null hypothesis that (Annex VI) + (Annex VI*Time Trend) = 0. I can reject the null hypothesis at 1% significance level.
[34] I check for the significance of the variable by testing whether the coefficient on the dummy and on the interaction term are jointly non-zero. The test does not allow us to reject the null hypothesis that these variable are jointly zero.

weather has a zero effect on the dependent variable. The estimator with these control specifications explains 95.25% of the presence of Sulfur Dioxide at ports.

The last model, *Model 3*, describes the results obtained when including port specific time trends. This means that I am now controlling for the trends of each individual port, allowing the estimator to yield more consistent and unbiased results. The coefficient on the variable of interest, total traffic, is still insignificant. The treatment effect of the regulations on port operations now yield a more consistent result as the estimator aligns with the assumptions of difference-in-difference models that each group over time has to present parallel trends. Nonetheless, this suggests that regulations on port operations do not limit pollution effectively.

Full Sample

Table 3 describes similar model specified in the previous table of result but applied to a sample group of 192 ports. When the sample used does not only consist of the busiest ports of the U.S., but also includes the smaller ones, the results show an overall increase in significance in the variable of interest *Total Traffic*. Furthermore, the coefficients on the air temperature variable in the previous sample are very insignificant. Thus, considering the unavailability of the data for all ports, the weather control is omitted from the regression.

Table 3 – Full Sample

Variables	Naïve Model	Model 1	Model 2	Model 3
Log(Total Traffic)	0.00568***	0.00625***	0.00558**	0.00325**
	(0.00208)	(0.00228)	(0.0224)	(0.00165)
Year – Time Trend	-0.0515***	-0.0477***	-	-
	(0.00107)	(0.00121)		
Annex VI (2005)	-	130.67***	-	-
		(17.39)		
Annex VI*Time Trend	-	-0.0651***	-	-

		(0.00867)		
Non-Road Tier 4 (2007)	-	29.23	-	-
		(22.89)		
Non-Road Tier 4*Time Trend	-	-0.0145	-	-
		(0.0114)		
Port operation policies	-	-	-0.02900	-0.0500
			(0.0276)	(0.0373)
Constant	104.3***	96.93***	1.577***	2.019***
	(2.144)	(2.433)	(0.477)	(0.0323)
Port Fixed Effects	No	Yes	Yes	Yes
Time Fixed Effects	No	No	Yes	Yes
Port Specific Time Trends	No	No	No	Yes
Observations	2,507	2,507	475	2,507
Number of Ports	192	192	25	192
R2	0.4508	0.9289	0.9525	0.9597

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

The *Naïve Model* suggests that total traffic has a significant positive effect on the quantity of SO2 measured in port areas. A 1% increase in tons of goods imported or exported by the port increases the presence of SO2 in the atmosphere by .568%. Contrarily the annual time trend decreases SO2 by 5.15%. The naïve model presents an R2 of 0.4508.

Model 1 presents the treatment effect of the two polices, IMO's MARPOL Annex VI and EPA's Non-Road Diesel Tier 4. The results yielded are consistent with the ones of the previous sample. The dummy variable showing the treatment effect of the IMO regulations has a significantly positive coefficient, while the EPA's is not significant. Considering the possibility of change in the trend over time, the policy implemented in 2005 has a significantly negative effect, decreasing the presence of sulfur dioxide by 5.7% in 2005.[35] The EPA policy instead did not yield significant results.[36]

When adding a treatment variable and fixed effects, total traffic in *Model 2* has a statistically significant positive coefficient of 0.00558. Thus, increasing SO2 presence by .558% per ton. The treatment variable shows instead a statistically insignificant effect. The estimator that includes fixed effects and a treatment variable has a considerably larger R2, explaining 92.88% of the variations in SO2.

I also control for the differences in the trends of SO2 concentrations across ports. I use port specific time trends to control for the possibility that sulfur dioxide counts follow different trends in each port over time. *Model 3* is the most specified model and is a consistent and unbiased estimator. In this case too, the total traffic has a significant positive effect. A 1% percent increase in tons of goods traded increase the presence of SO2 by 0.325%. Controlling for parallel trends allows to have an unbiased estimate of the treatment variable on the policies that regulate emissions from port operations. Although the coefficient increased in magnitude, it is still statistically zero. This estimator explains 95.97% of the percentage variations in SO2.

7 DISCUSSION

The regression models described in the previous section give insight on what is the true effect of increasing trade traffic, the significance of regulations on port operations, and on marine

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[35] This number is calculated from 100*((130.67) + (-0.0652*2005)) = -5.7%
I check for the joint significance of the two variables by testing for the null hypothesis that (Annex VI) + (Annex VI*Time Trend) = 0. I can reject the null at a 1% significance level.
[36]I check for the significance of its effect by testing whether the coefficient on the dummy and on the interaction term are jointly significant. The test does not allow us to reject the null hypothesis that these variables are jointly zero.

diesel sulfur dioxide caps on the presence of SO_2 in port areas. To understand this, it is necessary to first interpret and carefully analyze the results from the previous section. This can be done by initially looking at the coefficients of each estimation model, then comparing the results to examine the consistency of the outcomes of the estimators. These subjects will be thoroughly and objectively discussed in this section. This allows me to conclude with the policy implications that derive from this analysis.

7.1 Interpreting and Comparing Emission Estimation Results

The results obtained using the sample of the 25 major ports in the U.S. are compared to a larger estimator that uses all 192 commercial ports of entry. The results of the estimator with the larger sample are consistent with the ones yielded from the smaller sample. The consistency of the results state the reliability of the outcomes and of the conclusions drawn by this set of results.

When estimating sulfur dioxide emission with the models previously described with the sample of the 25 busiest ports, it can be noticed that the tons of goods traded do not have a significant impact on the air quality in the port areas. Traded quantities therefore would not seem to be significantly contributing to air quality depletion in port areas. However, the estimator consisting of 192 ports proves the opposite. In the sample of the 25 busiest ports, which are all in proximity of large metropolitan areas that also contribute to depletion of the air quality, maritime trade does not stand as a significant factor in increasing air pollution. This changes when other smaller ports in less populated areas are added to the equation. In these instances, traded quantities of goods are a relatively important contributor. From these results it is possible to conclude that growth in trade of the past decades did in fact have a significantly positive correlation with pollution in port areas. This reestablishes the important negative contribution that growth in trade has on the environment surrounding ports and it can be stated that trade does have an impactful ecological footprint.

The estimator also shows us the effect that clean port operation management regulations had on changes in SO2 levels in port areas. Even though port operations do contribute to pollution, it is clear from the results that the policies in place are not effective in reducing air pollution. According to the regression models, the treatment variable had a zero effect on SO2 levels. When the estimator includes port specific time trends to include the parallel trends assumption in the model, the coefficient of the difference-in-difference treatment still yields non-significant results. The treatments of each port are mostly Environment Management Systems and are based off protocols of the ISO 14001. It is possible to include all of them in one variable. Its coefficient proves the inefficiency and ineffectiveness of such regulations. Furthermore, the outcomes of the coefficient for the port operations treatment variable is consistent with the results obtained with the full sample. Clean management policies proved to be inefficient and non-impactful when looking at the levels of SO2 present in the atmosphere surrounding ports. These clean management policies have to be improved. The policy implications that derive from these results are discussed in the next section.

Levels of SO2 in the atmosphere of port areas has been significantly decreasing over time. The results yielded by the estimators consistently show that SO2 levels decrease at a rate of 5% to 6% percent. Thus, the annual time trend has a significantly negative time trend. It is possible to speculate that constant increase in climate change awareness and development in green technology has a powerful effect in decreasing sulfur count in the atmosphere of ports. Furthermore, the estimator measures the regression discontinuity present in the years 2005 and 2007, as well as the trend changes after these years. These are the years during which IMO and EPA regulation were implemented in the United States. When considering these policies as having an effect that is carried through time, the sulfur dioxide caps to marine fuels imposed by the IMO have a significantly negative effect between 5% and 15%. The Non-Road Diesel Tier 4 implemented by the EPA was not as effective possibly because ocean-going vessels were already complying with the sulfur dioxide caps previously imposed by the IMO. Enforcing limits on the amount of sulfur dioxide presence in marine diesel fuels appears to be an effective strategy.

7.3 Suggestions for Further Research

Although the data used is reliable and the results are reasonable and consistent with the true situation, there is still room for improvement in the study. Therefore, this analysis comes with suggestions to carry on studies further to achieve more in-depth results. The study groups the ports together and finds a common coefficient for the treatments introduced in each port. This model uses the assumption that each port authority was able to properly enforce these management regulations. After analyzing and studying each port that implemented their regulations and noticing the lack of transparency in showing concrete results in environmental safeguarding, I question how strictly their regulations were enforced. To study the possibility that some port authorities were not able to compel regulations, it would be possible to run a port by port study and analyze the effect on the environment of each regulation using monthly time data for more precise results. Doing an individual study for each port would allow to describe which policies were successful and which were not, analyze the causes and merits of each, and suggest the imitation of the successful ones by the rest of the ports.

8 CONCLUSION

Through the collected data and the estimators, the study proposes an estimate of what is the actual contribution of trade to sulfur emissions in commercials maritime ports in the United States. Together with analyzing this variable, the study researches whether the policies implemented are effective in reducing the ports' ecological footprint. The recap of these findings, will be included in this section, together with the policy implications and suggestions that come from this investigation.

8.1 Main Findings

I analyze the effect of trade on SO2 levels in port areas by using an estimator with data for a sample of the 25 busiest ports in the U.S. and compare that to the results of a similar estimator with a sample of all the commercial ports of entry of the U.S. The outcomes that the two samples yield are similar and consistent. The findings suggest a statistically significant positive effect of trade of the levels of SO2 in the atmosphere surrounding port areas. This element results significant especially in minor ports, which are not surrounded by large metropolitan areas. When using an estimator with 192 port, a 1% increase in tons of goods traded by a port increases the SO2 in the atmosphere by 0.32%. However, there has been a trend for SO2 levels to decrease over time. This negative trend could have been caused by an increase in awareness for the environment which spurred efforts to develop and use technologies that are more environmentally friendly. Moreover, we estimated the effects of the implementation of the MARPOL Annex VI in the U.S. and of the Non-Road Diesel Tier 4 regulation by measuring the regression discontinuities of the years 2005 and 2007. These dummies pick up more than the effect of the policies and present positive significant effects. When considering the effect of the policies over time, the treatments show a negative effect on sulfur dioxide presence in port areas. Only the IMO measure resulted being impactful according to all models and sample estimations. We also controlled for policies enforced by individual port authorities. The estimator showed that these initiatives did not have a significant effect. Regulations to safeguard the environment attempted by individual ports have been so far ineffective. This means that ports have been unable to enforce regulations, or that regulations on management practices are themselves not impactful. To research the possibility of these scenarios, I suggest studying each port individually. This will allow to investigate the flaws and qualities of each policy, and the circumstances that determine their success.

8.2 Policy Implications

Given these findings, it is clear that port authorities were not able to have a relevant impact on the air quality of the atmosphere surrounding ports. The most effective strategy is stimulating efforts to develop cleaner engines and fuels. The effects that caps on sulfur dioxide presence on fuels had on air quality proves this. These efforts allow ports to sustain the increase of trade that would otherwise negatively impact the environment surrounding them.

Clean management regulations for port operations enforced by port authorities are ineffective. These are publicized by ports to show their commitment to reducing their environmental footprint, but have no actual benefit to the environment. Port authorities should therefore focus on policies that reward shipping operators for the use of cleaner technologies. On the other side, international and national institutions, such as the IMO and the EPA, should continue imposing regulations to limit the use of outdated polluting engines and heavy bunker fuels.

9 APPENDIX

A1 – 25 port sample estimator with un-clustered standard errors

Variables	Naïve Model	Model 1	Model 2	Model 3
Log (Total Traffic)	0.0165	0.0124	0.0111	0.0201*
	(0.0107)	(0.0104)	(0.0102)	(0.0106)
Year - Time Trend	-0.0541***	-0.0483***	-	-
	(0.000983)	(0.0014)		
Port Operation Policies	-	-	-0.00707	-0.0437**
			(0.0159)	(0.0192)
Air Temperature	-	-	-0.000209	-0.000276
			(0.000260)	(0.000211)
Annex VI (2005)	-	142.89**	-	-
		(60.02)		
Annex VI*Time Trend	-	-.0719**	-	-
		(0.0299)		
NRD Tier 4 (2007)	-	57.42	-	-
		66.704		
Non-Road Tier 4*Time Trend	-	-0.0285	-	-
		(0.0332)		
Constant	109.2***	98.2***	1.969***	1.837***
	(1.908)	(2.831)	(0.210)	(0.217)
Port Fixed Effects	No	Yes	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes
Port Specific Time Trends	No	No	No	Yes
Observations	475	475	475	475
Number of Ports	25	25	25	25
R2	0.4338	0.9473	0.9525	0.9719

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

A2 – 192 port sample estimator with un-clustered standard errors

Variables	Naïve Model	Model 1	Model 2	Model 3
Log (Total Traffic)	0.00568***	.00625***	0.00558***	0.00325***
	(0.00135)	(0.00228)	(0.00132)	(0.00125)
Year - Time Trend	-0.0515***	-0.0476***	-	-
	(0.000471)	(0.001211)		
Port Operation Policies	-	-	-0.0281*	-0.0500**
			(0.0156)	(0.0201)
Annex VI (2005)	-	130.67***	-	-
		(17.38)		
Annex VI*Time Trend	-	-0.0651***	-	-
		(0.0087)		
NRD Tier 4 (2007)	-	29.22	-	-
		(22.89)		
Non-Road Tier 4*Time Trend	-	-0.0144	-	-
		(0.0114)		
Constant	104.3***	96.78**	1.918***	2.019***
	(0.944)	(2.424)	(0.0369)	(0.0503)
Port Fixed Effects	No	Yes	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes
Port Specific Time Trends	No	No	No	Yes
Observations	2,507	2,507	2,507	2,507
Number of Ports	192	192	192	192
R2	0.4508	0.9229	0.9289	0.9597

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

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