Measuring the Costs of Industrial Air Pollution:

A Cross-city Assessment of Research Methods, Models, and Governance.

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I. Aim: The aim of this project is to assess the effectiveness in the different industrial approaches to calculating the costs of industrial air pollutants. This is an extension of a previous *Asthma Files* project on the economic burdens of asthma in the United States which used similar methods and models to draw conclusions including the total expenditure as a percentage of United States GDP. The initial stage of research will examine a variety of methods for measuring the economic costs of air pollution. These methods can be divided into two core frameworks: (1) The impact pathway approach and (2) emissions market value. These frameworks have been applied to multiple air pollution studies.

Next, a look into the practice of these methods using case studies. These case studies will highlight three different approaches: (1) the impact pathway approach, (2) emissions trading, and (3) carbon offsetting. The case studies chosen have a macroeconomic focus to gain a broader understanding of the successes and failures of each. A more focused, microeconomic analysis will be done in further stages of this research to be applied to The Asthma Files 6 Cities Project.

The final stage of research will look at the 6 cities highlighted in The Asthma Files project: Albany, Bangalore, Beijing, Houston, New York City, and Philadelphia. There will be a deeper analysis of how/ if these cities use methods for calculating the costs of air pollution, how those methods are applied to air pollutant reductions, and if these programs have been successful. The final expenditures for each city will be reported in US dollars. This research will establish a framework for assessing how each of the 6 cities calculate air pollution costs and if there is a uniform approach using available data to calculate a total expenditure.

II. Introduction: Over the last 50 years air pollution has been a growing concern throughout the world. From the United States Clean Air Act of 1970 to the EPA's recently passed Clean Power Plan (Aug. 2015), air pollution has become a part of the political agenda. Even though air pollution and air quality are growing in importance, significant sustainable plans have yet to be put into place. Organizations ranging from the EPA to NGOs such as The Sierra Club, all aim to force political action and improve air quality.

A significant economic loss due to air pollution has potential to drive for such plans. By focusing on methods for evaluating the costs of air pollutants I hope to identify effective ways for measuring the cost of air pollutants and establishing a framework to enforce those methods.

The integration of economics into environmental policy work is a fairy new development. Quantifying the damage from emissions is even newer. As environmental issues become a part of political agendas, it is important to have an accurate measure of those issues as well as a convincing approach to addressing them.

1. The Cost of Air Pollution: Methods

1.1 Impact Pathway Approach:

Created in the 1990s between the European Commission and the US Department of Energy (USDA), the impact pathway approach "quantifies the damage costs imposed on society and the environment due to energy use" (European Environment Agency, p.18). This approach takes three core steps: (1) identify pollutant emissions, (2) determine impacts of emissions, and (3) quantify damage costs in monetary terms.

First, identifying pollutant emissions has the most variety in method. Depending on which industry is being assessed the pollutants will be different. Some of the most studied pollutants were: carbon dioxide, nitrogen oxides, sulfur oxides, ammonia, and particulate matter. Looking even further, most studies have separate methods for assessing carbon dioxide which will be covered in a further section of this report. Carbon Dioxide is well known as the primary greenhouse gas pollutant which has led to another method all together for addressing CO2 emissions (EPA, p. ES-1). The primary industries studied for emissions data included the energy sector, manufacturing combustion, production processes, transportation, and agriculture which consistently had a lower damage cost from emissions compared to other sectors.

Next, determine the impacts of emissions using value of life year (VOLY), value of statistical life (VSL), or productivity loss due to morbidity.

VOLY is “an estimate of damage costs based on the loss of life expectancy” (European Environment Agency, p.23). Simply put, in the case of this study when someone dies from air pollutant emissions, their value is calculated by their life expectancy subtracted by the age at which they died multiplied by their current or expected wage. This creates a value of life, a controversial measure that does not account for differences in wages or other environmental, economic and health factors. For example, the New York Times reported a 2010 value of life (not life year) to equal $9.1 million from the EPA, $7.9 million from the FDA, and $6 million from the transport department (New York Times). The variation in these values alone demonstrate the difficulty in finding consensus when calculating the VOLY.

The value of statistical life is another controversial method that puts a value on a human life but take a different approach from the VOLY. VSL is derived from “individuals’ valuation of the willingness to pay to reduce the risk of dying” (OECD). To calculate the VSL one must start with a survey to determine how much individuals are willing to pay to reduce their risk of dying from air pollutant related illnesses. This willingness to pay for reduce risk becomes the value of one life. In the OECD study on the cost of air pollution, they multiplied the VSL with the amount of deaths due to air pollutions to calculate a total expenditure value.

Productivity loss due to morbidity is a more complicated measure when calculating the cost of air pollution. According to the OECD, there is a lack of standard methods for estimating the cost of morbidity (OECD). Most studies that include productivity loss due to morbidity use a similar approach to the VOLY, but instead of using life expectancy they use loss of time working which creates a much smaller total expenditure. The significance in including morbidity as well as mortality, even though the expenditure difference is large is to include sick days due to air pollutions. How many individuals miss work because of air pollution? Morbidity can be used on a micro scale to assess annual losses by each employee of a certain company due to their air pollution related illness.

Lastly, quantifying damage costs in monetary terms is combined within the last three methods described. The ultimate goal is to calculate a dollar value for measuring industrial air pollution. VSL, VOLY, and productivity loss due to morbidity make that possible.

Throughout the literature reviewed for this research, the impact pathway approach has been apparent as a method for quantifying a variety of pollutants from different sectors. The Organization for Economic Co-operation and Development study on the cost of air pollution from transport uses this very method to quantify a final expenditure. They (1) identify pollutants: NH3, nitrogen oxides, non-methane volatile organic compounds, particulate matter, and sulfur oxides. Then (2) determined the impacts of emissions using VOLY data. And finally (3) quantified the damage in monetary terms as a final expenditure range of 329 billion EUR_{2005} – 1053 billion EUR_{2005} (OECD).

1.2 Emissions Market Value Approach:

The emissions market value approach includes two methods for calculating the costs of air pollution using market values for the resource itself. The first approach is the Emissions Trading System (ETS), a cap and trade approach to carbon emissions. Second, is a similar approach know as, “carbon offsets”. It is important to note that the following methods are currently primarily focused on carbon and beginning to be used for other air pollutants.

The ETS was created by the EU in an effort to address climate change and increasing CO2 emissions. It is an international system for trading emissions allowances. The EU sets a cap for the amount of total CO2 emissions allowed, companies are then given carbon allowances that cover their emissions. If a company exceeds their carbon allowance they are fined a great amount. If a company falls under their allowance, they can either save the allowances until next year, or sell to another company that may need more allowances. The EU lowers the cap after a certain amount of years to ensure reduction of emissions.

This cap and trade system of emission allowances sets a market value on carbon emissions. Depending on the cap, there is a monetary value for each allowance to be bought or sold. That monetary value is what is then used to calculate the cost of CO_2 in an economy. In other words the cost of emissions to an economy are equal to the ETS allowance market equilibrium price.

This idea of 'trading' emissions is growing to other countries outside of the EU. It is an interesting model for reducing carbon and encouraging energy efficiency within companies. One major issue faced within the carbon allowance market is the volatility of the global economy. The global economic crisis following the 2008 US recession led to companies focusing less on emissions and more on production. It became too expensive for some businesses to maintain low carbon emissions and purchase more allowances.

The second market method is very similar to the cap and trade system in the sense that emissions are being commoditized. Carbon offsets value carbon emissions in the amount of money it takes to offset the environmental impacts of those emissions. For example, if one owned a coal plant with a certain number of CO_2emissions, how many trees could they pay someone to plant offsite to absorb the CO_2 emitted, and how much would it cost? That cost is considered the value of emissions according to the carbon offset model.

Growth in this model has gone beyond coal and trees, now industries can choose to offset their carbon by paying for initiatives such as wind farms, household device projects, forest protection from illegal logging, methane capture from landfill gas and agriculture, and reforestation because these projects reduce carbon and offset the

damage to the environment. There are many flaws when using this method to value emissions. The primary issue with carbon offsetting is that it simply offsets the externalities from industry and does not promote more efficient/ cleaner emission reduction tactics. While this method has potential for measuring the costs of air pollution, by defining a monetary value for carbon, it is not ideal when health is a variable used to calculate expenditure.

1.3 Case Study: Methods

The first case is global emissions trading starting with the EU's ETS program, a cap and trade system for reducing industrial air pollutant emissions. The details of the methods behind the ETS have been described in the Emission Market Value Approach section of this paper. The following analysis will assess the growing global market for emissions and its overlap with the current Asthma Files 6 Cities.

The EU's emissions trading scheme is currently the largest of its kind. "EU ETS is the first cross-border tradable permit or emissions trading scheme to address greenhouse gas (GHG) emissions, covering almost 11,500 installations or about 45% of total CO_2 emissions in the EU" (Egenhofer). This program has begun to grow to other regions. The EU hopes to eventually have global emissions trading network that can help reduce global emissions.

The next case looked into is the practice of the impact pathway approach. The approach was used to identify industrial SO2 pollution and agricultural losses in China. The study was conducted by the University of Science and Technology in China. In the study they examined "the correlation between per capita number of state monitored enterprises and other socioeconomic indices to show the negative impacts of sulphur

dioxide (SO_2) industrial air pollution on agricultural development in the regions" (Wei, p.1)

This research followed the impact pathway approach exactly. The identified pollutant SO_2 demonstrated a correlation with agricultural loss/ damage, and the results were expressed in monetary terms. Looking deeper into the methods, they chose to use the human capital approach instead of valuing a life year. The SO_2 data was found using air quality monitoring stations placed throughout China. Using a dose-response function they could calculate the dose from the increased amount of pollutants in terms of the dose of impacts, or damage to agriculture. From there they put those impacts in monetary terms for a final loss equal to 1425.907 million US dollars in 2008.

1.4 Conclusion:

The better method for calculating the costs of industrial air pollution for the Asthma Files 6 Cities research group is the impact pathway approach because it leaves room to account for health when measuring final costs. The market value approach does not include correlations to health impacts of air pollution which makes it ineffective for this research group. While the market value approach may show more implementation and concrete (positive) results, the impact pathway approach is a firm framework for looking into the costs of industrial air pollution in terms of asthma.

Moving forward in this research I will use the impact pathway approach to calculate the costs of industrial air pollution of the 6 cities being researched by the asthma files group. This research will strive to include commonly accessible data across each city, asthma as the health factor when calculating the value of a life year, and a correlation between industrial air pollutants and asthma itself.

2. Data

2.1 The Six Cities

The Asthma Files 6 Cities include the following: Albany, Bangalore, Beijing, Houston, New York City. These cities were selected by the research group due to available academic resources within each of the cities. It is important to note that four of the six cities fall within the United States. Due to the lack of city specific VSL and ambient air pollution attributable death data, the total cost for each of these cities will be the same. This issue has also led to the resulting total cost of air pollution using the impact pathway approach to be expressed on a country, not city level. The following sections delve deeper into this issue of commonly accessible data for all six of the researched cities.

2.2 VSL

As described above the value of a statistical life is a risk assessment model for calculating the total cost of one human life using cost benefit surveys within the population. The data used for this analysis came from the Ted R. Miller's 1999 study titled: Variations between Countries in Values of Statistical Life. This study pooled VSL data from 68 studies across 13 countries to calculate the income-elasticity of values across countries (Miller, p. 169). He used the following log regression equation to estimate income elasticity:

$$\ln(VSL) = a + b\ln(Y) + cZ$$

VSL: Value of Statistical Life, Y: income measure, Z: vector of explanatory variables, a,b,c: vector of regression coefficient (Miller, p.173)

Miller then applied this regression model to estimate VSLs for additional countries (Miller, p.181). The results of Miller's analysis can be seen in figure 1 on the following

page. For this study, best estimate VSL for China, India, and the United States in 1995 US dollars will be used. An important note is that both China and India have VSL estimates projecting beyond the range of the data.

Table 5

1997 GDP/Capita, VSL Range, and VSL Range as a Multiple of GDP/Capita for Selected Countries

(thousands of 1995 US dollars)

	GDP/Capita	Measured	Range for VSL		Best Estimate	Range as Multiple	
			Low	High		Low	High
WORLD	4,608		630	900	650	137	195
NORTH AMERICA	16,435		1,600	2,600	2,190	97	158
EUROPEAN UNION	20,714		2,500	3,600	2,730	121	174
Argentina	8,720		1,000	1,500	1,200	115	172
Australia	20,316	2,126	2,100	3,100	2,680	103	153
Austria	24,481	3,253	3,100	4,500	3,200	127	184
Belgium	22,824		2,900	4,100	3,000	127	180
Brazil	4,820		500	900	680	104	185
Canada	19,225	3,518	2,100	3,100	2,540	109	161
Chile	4,598		600	900	650	124	191
Czech Republic	4,839		500	900	680	110	184
Denmark	30,834	3,764	3,800	5,000	3,990	124	162
Finland	22,340		2,300	3,400	2,930	103	152
France	22,795	3,435	2,900	4,200	2,990	127	184
Germany	24,406		3,100	4,600	3,190	127	188
Greece	10,950		1,100	1,800	1,490	100	164
Hong Kong	24,147		2,600	3,800	3,160	108	157
Hungary	4,275		600	900	610	133	204
Ireland	19,194		1,600	3,000	2,540	83	156
Israel	16,127		1,700	2,600	2,150	105	161
Italy	19,081		2,100	3,000	2,520	110	157
Japan	36,399	8,280	4,400	7,000	4,680	121	192
Kuwait	16,929		1,900	2,800	2,250	112	165
Malaysia	4,321		500	900	610	125	199
Mexico	3,529		500	800	500	130	235
Netherlands	22,307		2,800	4,000	2,930	126	179
New Zealand	15,100	1,625	1,600	2,400	2,020	106	159
Norway	33,360		4,000	5,200	4,300	120	156
Peru	2,490		300	800	360	129	317
Poland	3,362		400	800	480	113	241
Portugal	9,758		1,200	1,600	1,330	123	164
Russia	2,556		300	800	370	121	305
Saudi Arabia	6,899		900	1,200	960	136	175
South Africa	2,862		400	800	410	143	290
South Korea, 1997	10,063		1,200	1,700	1,370	119	169
South Korea, 1985	2,630	620	400	800	380	143	306
Spain	12,965		1,500	2,200	1,750	116	170
Sweden	24,670	3,106	2,800	3,900	3,230	113	158
Switzerland	34,397	7,525	4,200	7,400	4,430	122	215
Taiwan, 1997	12,457		1,400	2,000	1,680	112	161
Taiwan, 1985	5,901	956	800	1,100	820	139	186
Thailand	2,614		400	800	380	145	310
Trinidad	4,421		500	900	630	118	195
Turkey	2,854		300	800	410	133	284
United Kingdom	20,831	2,281	2,100	3,200	2,750	101	154
United States	28,206	3,472	3,300	4,500	3,670	117	160
Uruguay	5,857		700	1,100	820	121	179
Venezuela	3,678		400	800	520	114	223

Table 5 Continued

1997 GDP/Capita, VSL Range, and VSL Range as a Multiple of GDP/Capita for Selected Countries

(thousands of 1995 US dollars)

	GDP/Capita	Measured	Range for VSL		Best Estimate	Range as Multiple	
			Low	High		Low	High
PROJECTING BEYOND THE RANGE OF THE DATA							
Bangladesh	252		30	700	40	131	2,762
China	703		100	700	110	142	995
India	379		50	700	60	124	1,845
Indonesia	1,059		100	700	160	128	687
Jamaica	2,357		200	800	340	88	318
Nigeria	249		40	700	40	145	2,798

Note: GDP per capita from OECD and US Department of State web sites.

Figure 1. Estimated VSL values for countries using Miller's regression model found within: Variations between Countries in Values of Statistical Life. (Miller, p. 180-181)

2.3 World Health Organization Data

The World Health Organization data on Ambient Air Pollution Deaths is the only source found directly linking air pollution to mortality on a regional scale. I an effort to follow the criteria for an effective impact pathway approach this data was chosen for two reasons. First, the World Health Organization addresses the correlation between air pollution and mortality. Looking into the study they find correlations between increased particulate matter and cardiovascular disease expressed by regions which include all six cites. Throughout this research it has been a reoccurring issue to find common data for both VSL and mortality due to air pollution for all six of the cities being researched. Figure 2 below shows the WHO results and total mortality due to ambient air pollution within the WHO regions and World Bank income Categories. The data used in this study includes the ambient air pollution attributable deaths in 2012 for the following regions: Region of the Americas, South-East Asia Region, and the Western Pacific Region. While useful in finding common data, the regions propose a problem for generalized results. The aim of this study is to identify the six cites cost of air pollution, using regional data divided into income categories proposes a significant problem for the results.

WHO region	Ambient air pollution attributable deaths per 100'000 children under 5 years[i]	Ambient air pollution attributable deaths[i]	Ambient air pollution attributable deaths in children under 5 years[i]	Ambient air pollution attributable deaths per 100'000 capita[i]
	2012	2012	2012	2012
Africa	31	175700 [145100-211100]	45300	20
Low- and middle-income countries of the Americas	2	57600 [16600-135800]	800	10
South-East Asia	23	936300 [761500-1157500]	40800	51
Low- and middle-income countries of the European Region	7	202700 [168300-248300]	1400	75
Low- and middle-income countries of the Eastern Mediterranean Region	35	236000 [202000-277400]	24200	42
Low- and middle-income countries of the Western Pacific Region	12	1669400 [1289400-1955700]	14100	102
Global	19	3732500 [3187700-4290900]	126800	53

3. Analysis

The impact pathway approach links air pollution to a total expenditure. Using commonly accessible data that included the six cities researched, a total cost of ambient air pollution was calculated in 1995 US dollars and then converted into 2012 US dollars using the Consumer Price Index.

City	Country	VSL (Million 1995 US Dollars)	WHO Region	Ambient Air Pollution Attributable Deaths (2012)	Total Cost (Million **1995 US Dollars)**	Total Cost (Million **2012 US Dollars** rounded to nearest dollar**)**
Albany	United States	3.67M	Region of the Americas	57600	211392M	318,467M
Bangalore	India	0.06M	South-East Asia Region	936300	56178M	84,633M

Beijing	China	0.11M	Western Pacific Region	1669400	183634M	276,649M
Houston	United States	3.67M	Region of the Americas	57600	211392M	318,467M
New York City	United States	3.67M	Region of the Americas	57600	211392M	318,467M
Philadelphia	United States	3.67M	Region of the Americas	57600	211392M	318,467M

4. Results

The highest total estimated cost of ambient air pollution mortality for a country is in the United States with about 318 million 2012 US dollars. China has the second highest estimated cost at 277 million 2012 US dollars. India has the lowest estimated cost with just about 85 million 2012 US dollars. These figures express only the country level data which can be only compared to other country calculations. To identify specific city costs, there is a need for more uniform data available globally on both VSL and air pollution mortality. The initial hypothesis proved incorrect. There is insufficient data to accurately measure the cost of air pollution across each of the six cities. The following discussion section goes further into the need for commonly accessible data as well as if that data can be applied on a city level.

5. Discussion

The ongoing issue with this research has been the lack of city level data available. Another approve in finding such data might be looking into six separate city specific methods for calculating the cost of air pollution. This does however open the floor for a less uniform approach to apply to other cities throughout the world. Moving forward with

this study, it would be interesting to measure the significance of the results up against other ambient air pollution studies.

Looking at the cost of air pollution can be an effective way to influence policy. If there were a globalized monitor system to collect health statistics as well as emissions data, the theories and methods applied here could be taken to a variety of cities. Another issue that is common within most economic analysis is the issue of variables. While this study does calculate a total cost, there are health, social, geographic, and political factors that can affect the final results.

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