Urban Air Quality and Human Health in Latin America and the Caribbean

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October 2005

Washington, D.C.

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URBAN AIR QUALITY AND HUMAN HEALTH IN LATIN AMERICA AND THE CARIBBEAN

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Executive Summary

Recent estimates indicate that over 100 million people in Latin America and the Caribbean are exposed to air pollution levels exceeding World Health Organization guidelines. This figure does not include the millions of individuals who are exposed to indoor air pollution due to biomass burning and other smaller scale sources, especially in rural areas. Health problems due to poor air quality have been among the main environmental concerns in Mexico City, Santiago, Bogotá, Sao Paulo, Lima, Quito among other cities in the region. During the last two decades, several countries in Latin America have begun to deal more seriously with this environmental problem. In addition to strengthening environmental institutions and upgrading environmental measurement systems, environmental standards have been imposed throughout the region, especially for industries, new and old vehicles, and fuel quality.

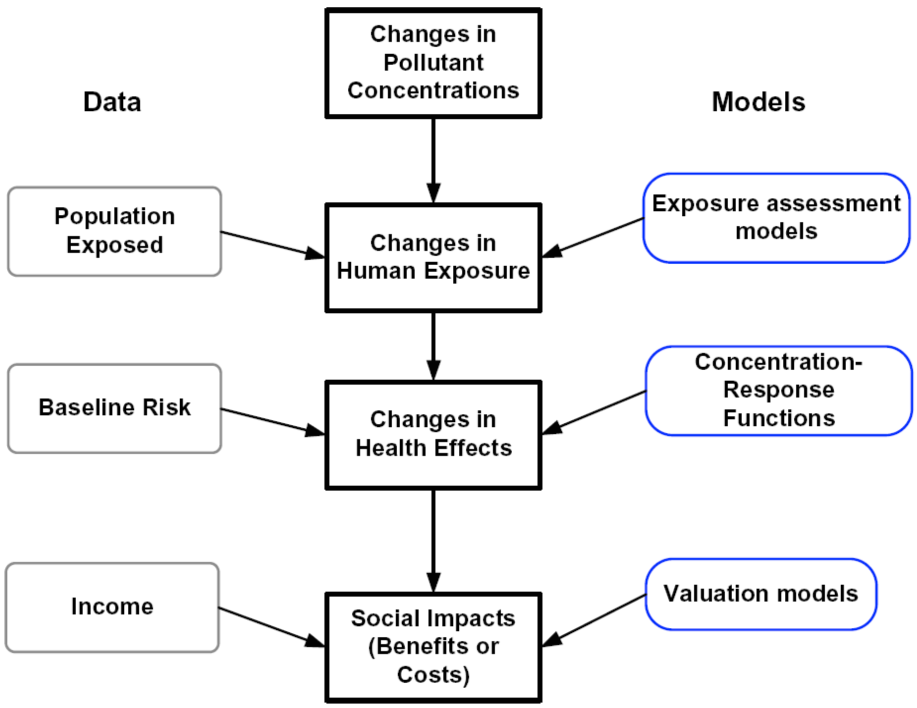
Despite this progress, however, the level of knowledge about air pollution's impact on health is limited in much of the LAC region, even though it is considered a medium to high priority issue. Information on air quality remains limited and of uncertain quality in a number of locations. Moreover, the social costs of health damages from urban air pollution have not yet received systematic study except in a few locations.

This study provides quantitative estimates of key air pollution concentrations, health impacts, and the monetary value of improving air quality in 41 major LAC urban areas containing 100 million people in all. While the estimates we derive are necessarily incomplete and uncertain, they allow comparisons across cities and show the significance of air quality improvements for the region as a whole. From a policy perspective, the estimates highlight the real economic value of improvements in urban air quality and give policy analysts a basis for analyzing policies and abatement measures for their net benefits to society.

"Integrated Assessment" Approach

The approach taken in this study is an example of what is known by policy analysts as "integrated assessment" using a "damage function" approach. An integrated assessment is a multidisciplinary, multi-step modeling approach to problems, in this case to the estimation of economic and physical benefits to health of air pollution improvement. The integrated assessment approach is shown in Figure E-1.

Figure E-1 Damage Function Approach



This approach involves a series of interlocked components beginning with changes in ambient air pollution concentrations and ending in societal benefits, using data and models drawn from government institutions and the academic literature. This report is organized by these components.

Scope of the Study

For this study we use data on particulate matter (PM-10, specifically). Reasonably plentiful and usable data are available for this pollutant, and it is strongly identified with problems of illness and premature mortality based on a large international epidemiology literature. While there are many air pollutants that can cause health problems, the pollutants of higher concern in LAC are particulate matter and ground level ozone precursors.[*] However, usable ozone data are scarce in Latin America, and in those locations where data are available, the benefits of PM-10 reduction appear to be on the order of 10 times greater than the benefits of ozone reduction. These figures

[*] Lead from motor fuel is another serious threat to public health, but the region has already made considerable progress in reducing fuel lead levels and data on blood lead levels were not readily accessible to us. We also recognize that hazardous air pollutants are present in most Latin American cities; however, there is no systematic information on the importance of these pollutants in the different cities.

suggest that the downward bias in our estimates from exclusion of ground level ozone impacts is not too large.

Scenarios

To represent the variety of different information sources and uncertainties surrounding our analysis, we constructed several scenarios. We consider two air quality improvement scenarios: (C1) a uniform reduction of 10% in the annual ambient concentration of PM_{10} in each city; and (C2) a scenario in which each city complies with a reference concentration equal to the current US annual standard for PM_{10} (50 $\mu g/m^3$). Under scenario (C1) every city cuts emissions; the cities with the highest baseline make the largest pollution reduction. Under scenario C2, the cities with concentrations already below the standard do nothing. Since the cities above the standard in this case generally have quite poor air quality, the reductions in these cities are well in excess of those in C1.

To calculate health impacts of the two air quality improvement scenarios, we used two different pools of statistical information on public health. (E1) Latin American studies; and (E2) application of U.S. models to our Latin American cities. The results in E1 may be more likely to reflect actual conditions in Latin America, but the U.S. based analysis E2 is more comprehensive.

To calculate the economic benefits of improved air quality, we similarly considered two possible sets of information: (V1) results from a still limited set of economic valuation studies in Latin America, and (V2) application of valuations from the U.S. to the Latin American cities, after adjusting for income differences to re-scale the U.S. values. We also considered in each case two different definitions of economic value. The more conservative measure considers only the direct savings in the overall social cost of illness (COI): avoided medical costs and lost productivity from illness. The more comprehensive and theoretically preferable economic measure includes as well imputed values of indirect, “quality of life” benefits, notably the benefit enjoyed by everyone in a cleaner environment of a reduced risk of premature death. Assessing such benefits is more complex and controversial, but they are as or more important in the assessment of a society’s “willingness to pay” (WTP) for improved air quality as the direct savings from illness costs.

Key Findings

Figure E-2 shows the kinds of reductions in particulate matter implied by our two air quality scenarios. Our survey of available air quality data indicates that 26 cities, containing 85 million people (of which 28 million are children less than 18 years of age) out of the almost 100 million population of the cities considered in the study, are exposed to particulate concentrations above internationally accepted levels. For many of them (18 million, 6 of them children), the excess is notably large (more than twice the US standard). We must also note, however, that for many of the cities we have considered, particulate data are of very uncertain quality. For almost all cities, moreover, data on ground level ozone or its precursors is very elusive. Based on the general principle that good policy flows from good data as well as sound analysis, improvement in air quality monitoring in Latin America should be a higher priority than it evidently is at the present time.

The physical effects on health of these excess pollution levels also are quite significant. If we look only at cities with PM concentrations above the U.S. standard, reducing concentrations to the level of the standard would avoid on the order of 10,500 to 13,500. premature deaths as well as well a host of illness incidents, reduced activity days, and lost productivity. The premature deaths avoided from this air quality improvement would occur across the age distribution but would be especially important for more sensitive elder and child populations (by some of our estimates, 10,000 and 2,500 excess deaths avoided in these groups, respectively). The total premature deaths avoided would be on the order of 2 to 2.6% of total deaths per annum in the cities considered.

Health improvements occur not just from reducing PM concentrations to meet the U.S. standard but also through further improvements below the standard. Our simulation of a 10% reduction in concentrations in all cities also led to large reductions in illness and premature mortality, with benefits spread out over the range of cities. Indeed, for this scenario the deaths avoided in cities meeting the standard are 12 to 25% of total deaths avoided, suggesting that just meeting the U.S. standard should not automatically be seen as an adequate goal. These relatively significant health benefits are predicted whether one relies on epidemiological studies from Latin America or on extrapolated application of U.S.-based studies (the latter predicts even larger health improvements, on the order of 30% more).

Figure E-2. Baseline and two control scenarios for PM_{10}

Concentration reductions, by city ($\mu g/m^3$ annual average)

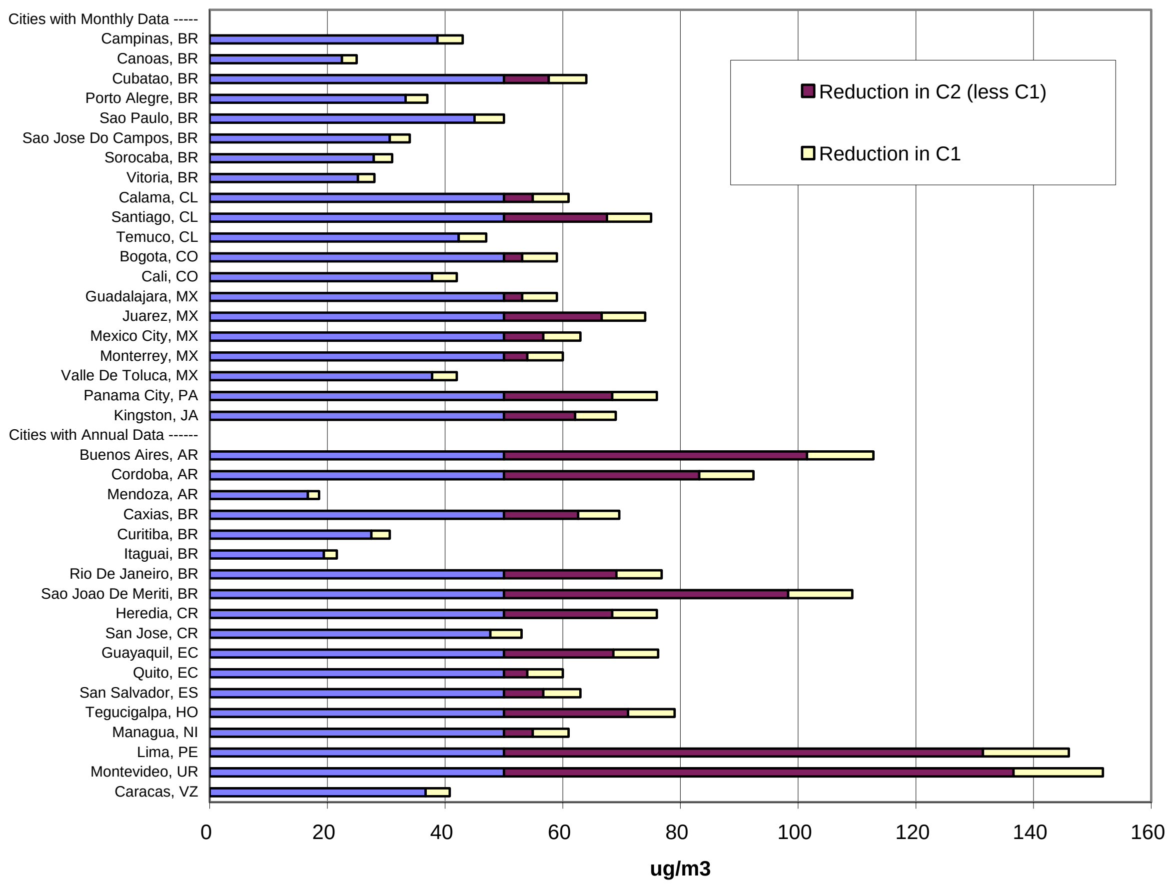


Table E-1 below summarizes the findings of the economic analysis. The valuations based on a combination of U.S based health impacts models, and transfer of U.S valuations to Latin America, exceed those based only on Latin American health models and valuations by a factor of approximately 12 for the more inclusive Willingess to pay estimates, and 17 for cost of illness estimates. This further highlights the need to develop better estimates of Latin American valuations comparable to the more comprehensive U.S based measures. The findings also are sensitive to the difference between direct cost savings and the more comprehensive willingness to pay measure for valuing health improvements. Economic analysis makes a solid case for use of the broader and more inclusive measure. But the more intangible benefits do not register in the national accounts, for example, and with scarce resources there may be some pressure in the policy process to scale investments in air pollution control to the more modest level implied by cost of illness assessments of benefits.

Even this more limited measure of benefits is significant if we use the more inclusive U.S. COI figures. According to our analysis, about $2.2B or $6.2B per annum in COI benefits might be realized, depending on the pollution control scenario. Such figures could justify significant investments in pollution control as a form of public health protection. The WTP measures average to roughly 0.4-1.4% of income over all the cities, a nontrivial valuation by any measure.

Table E-1 Summary of economic benefits

(a) Total benefits (MUS$/year)

Benefits measure	Scenario*	Uniform 10% PM reduction			Meeting USEPA standard		
WTP							
	LAC	1,100	670	**1,700**	1,900	3,300	**5,200**
	USA	11,000	8,900	**20,000**	16,000	49,000	**66,000**
COI							
	LAC	73	52	**130**	130	260	**390**
	USA	1,100	1,100	**2,200**	1,800	4,400	**6,200**

(b) Per capita benefits (US$/person/year)

Benefits measure	Scenario*	Uniform 10% PM reduction			Meeting USEPA standard		
WTP							
	LAC	17	18	17	44	103	70
	USA	175	245	201	374	1,531	883
COI							
	LAC	1	1	1	3	8	5
	USA	17	30	22	42	137	83

(c) Benefits as Percentage of Income (%)

Benefits measure	Scenario*	Uniform 10% PM reduction			Meeting USEPA standard		
WTP							
	LAC	0.3%	0.5%	0.4%	0.8%	2.9%	1.4%
	USA	3.3%	6.5%	4.3%	6.4%	43.4%	18.1%
COI							
	LAC	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%
	USA	0.3%	0.8%	0.5%	0.7%	3.9%	1.7%

*Note: "LAC" refers to health impact and economic valuation estimates constructed using information from studies in Latin America and the Caribbean. "USA" refers to health impacts and valuations transferred to Latin America from U.S. based studies.

Notwithstanding the range of estimates we present and the largely unquantifiable uncertainties excluded from this range, the results provide a call to action for controlling urban air pollution in Latin American cities. What forms this action should take goes beyond the scope of this study. However, in Santiago Chile, where cost benefit assessment has been used to screen air quality improvement options, benefits information of the type we have generated has been used with cost information to lay out a menu of potential interventions. These include new emission standards for fixed and mobile sources (new buses, trucks, and automobiles), the retrofit of existing diesel vehicles with particle traps, the introduction of very-low sulfur diesel fuel, and the introduction of an emissions cap and trade system to improve efficacy and cost-effectiveness of emissions limitations for fixed sources.

The cost-effectiveness of different interventions is sector and country-specific. Generally, simple PM filtration measures at stationary sources can be cost effective, as can be some targeted measures to reduce emissions from older diesel vehicles or to introduce low sulfur diesel fuel. How far these and other interventions can be taken while still yielding net benefits – and widely shared benefits – requires more detailed analysis of mitigation costs. What our analysis may offer from a policy perspective, among other points, is a stronger rationale for investigating policy options and then robustly implementing those policies that can be justified.

I. Introduction

Recent estimates cited in a survey conducted by the Pan American Center for Sanitary Engineering and Environmental Sciences (PAHO 2000) indicate that over 100 million people in Latin America and the Caribbean are exposed to air pollution levels exceeding World Health Organization guidelines. This figure does not include the millions of individuals who are exposed to indoor air pollution due to biomass burning and other smaller scale sources, especially in rural areas. During the last two decades, several countries in Latin America have begun to deal more seriously with this environmental problem.[1] In addition to strengthening environmental institutions and upgrading environmental measurement systems, environmental standards have been imposed throughout the region, especially for industries, new and old vehicles, and fuel quality.

Despite this progress, however, the level of knowledge about air pollution's impact on health is limited in much of the LAC region, even though it is considered a medium to high priority issue. Information on air quality remains limited and of uncertain quality in a number of locations. Moreover, the social costs of health damages from urban air pollution have not yet received systematic study except in a few locations.[2] Our aim in this study is to shrink this information gap by providing quantitative estimates of air pollution concentrations, as well as health effects and the monetary value of improving air quality in 41 major LAC urban areas containing 100 million people in all.

While the estimates we derive are necessarily incomplete and uncertain, they allow comparisons across cities and show the significance of air quality improvements for the region as a whole. This study is the first to collect and analyze together virtually all of the accessible air quality, health and economic valuation data from Latin America. We also utilize health and economic valuation data from the U.S., adjusted to apply to Latin America, in order to provide additional perspective on the benefits of air quality improvements. From a policy perspective, the estimates highlight the real economic value of improvements in urban air quality and give policy analysts a basis for analyzing policies and abatement measures for their net benefits to society.

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[1] Health problems due to poor air quality have been among the main environmental concerns in Mexico City, Santiago, Bogotá, Sao Paulo, Lima, Quito among other cities in the region.

As reported in Section VII of the paper, we find that economic benefits of air quality improvement are significant in terms of both reduction of disease incidence and economic well-being. To put these findings into a broader perspective, the Global Burden of Disease (GBD) project has identified environmental risks as a significant component of the overall burden of disease (Ezzati, Lopez et al. 2002). Depending on gender and on the health impact measure used, environmental risks generally are roughly 4-5% of the total burden of disease risk for a group of relatively higher income countries in Latin America and the Caribbean, and 7-9% for a group of relatively lower income countries (including Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, and Peru). This makes environmental risks roughly comparable to childhood and maternal under-nutrition and ahead of sexual and reproductive health risks, though behind (for men) addictive behaviors like smoking.

The largest single environmental component is unsafe water, sanitation, and hygiene – especially in the poorer country group. Urban air pollution in and of itself is a smaller component of the overall environmental risk. However, when the GBD looks globally (not just in Latin America) at leading causes of disease, lower respiratory disease ranks second, right behind HIV. Since dirty urban air can aggravate sensitivity to other airborne health threats (including smoking and dirty cooking fuels), interventions to improve air quality have overall impacts beyond their direct effects by reducing the severity of other health insults.

I.A The Fundamentals of Economic Analysis for Air Quality Improvements

I.A.1 Cost-of-Illness Measure of Air Quality Improvement Benefits

Cost-of-illness estimates typically include direct medical expenditures and forgone wages associated with illness and premature death. Often, the value of lost household services is included as well. This approach -- also known as the human capital approach when it addresses premature deaths -- does not purport to be a measure of individual or social welfare, since it makes no attempt to include intangible but real losses in well-being, such as those associated with pain and suffering. Its advantage is that it is relatively simple to calculate and understand. Historically, this has been an important approach used to calculate monetary costs associated

2 These include Santiago, Mexico City, and Sao Paolo, as discussed below.

with illness and death. The U.S. Department of Agriculture (USDA) and the Centers for Disease Control and Prevention (CDC), in particular, feature this measure in their cost-benefit analyses (Buzby, Roberts et al. 1996). The USDA has recently issued a Cost of Illness Calculator ((Economic Research Service - USDA 2003) for application to food borne illnesses. Cost-of-illness measures are generally at least several times lower than WTP measures for the same health effect, because of their exclusion of intangible values (Kulcher and Golan 1999).

I.A.2 Willingness to Pay (WTP) Measure of Air Quality Improvement Benefits[3]

The WTP approach is a benefits-based measure versus the limited cost-based COI approach. It is rooted in on the tradeoffs that individuals make between health and wealth or income (or other goods). Such tradeoffs in daily life are easily recognized and sometimes observed. For example, if a person is running late to a meeting he may drive faster, knowing that the increased speed carries with it a slightly increased chance of accident and possibly death. Or a person may take a riskier job if he knows the pay will be higher to compensate for the greater accident risk (or the converse: he may be content with a less risky job making lower wages).

WTP values can be divided into those measuring preferences for reductions in the risk of premature death, and those measuring preferences for reductions in morbidity (illness) risk. Morbidity can be divided into acute effects and incidence of chronic disease. For valuation purposes, the acute effects are usually modeled and estimated as though they are certain to be avoided, whereas the chronic effects are usually treated in the same way as for mortality i.e., as a reduction in the risk of developing a chronic disease.[4] Values to reduce acute effects, the probability of chronic effects and the probability of premature death are usually added up, with some minor adjustments to avoid obvious double-counting.[5]

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[3] Another measure of preferences consistent with welfare economics is willingness to accept (WTA). This approach has been difficult to implement in practice because of ethical issues (e.g., how much money would you accept to not have your risks reduced) and technical reasons, i.e., your answer in unbounded by income so dispersion of answers tends to be very wide. Consequently, WTP is the preferred measure.

[4] Estimates of the WTP for mortality risk reductions are sometimes converted to a "value of statistical life" (VSL) by dividing the WTP by the risk change being valued. Similarly, the value of a statistical case of chronic illness is (the WTP for a risk reduction in chronic illness)/(risk change).

[5] Recently, DeShazo and Cameron (2003) have administered surveys that ask for preference rankings over lifecycle-based health effects and mortality risks, offering the possibility of monetizing preferences for mortality and morbidity holistically.

WTP studies attempt to estimate economic benefits based on individual preferences either by uncovering the tradeoffs people actually make (revealed preference (RP)) or by presenting people with hypothetical but realistic choices in a survey-based approach (stated preference (SP)). The revealed preference approach involves examining behavior, either in the marketplace or elsewhere, to discern WTP. There are a wide variety of revealed-preference approaches. The most developed technique for estimation of health and mortality risk reduction benefits is probably the hedonic-labor-market approach and the property-value approach. The most common RP approach, and the approach whose studies have traditionally under girded VSL estimates used by the government in CBAs, is the hedonic-labor-market approach. This approach involves estimating the wage premiums paid to workers in jobs that have high risks of death (Viscusi 1992; Viscusi 1993; Viscusi and Aldy 2002).

Under the stated preference approach, two approaches are in use. Contingent valuation (CV) studies pose questions about the willingness to pay (WTP) for a change in risk of an adverse health outcome. A newer alternative to CV is conjoint analysis, which is used extensively in marketing to elicit preferences for combinations of product attributes. When such analyses involve the attribute of a price, the value placed on other attributes can be estimated.

SP and RP methods have been most extensively used to estimate WTP for reductions in risks of death. The SP methods involve placing people in realistic, if hypothetical, choice settings and eliciting their preferences. In CV surveys, individuals are not asked how much they value life *per se*, because WTP to avoid certain death is limited only by wealth. However, as has been observed in many cases, people are willing to make tradeoffs between marginal changes in risk and wealth. These choices might involve alternative government programs or specific states of nature, such as a given reduction in one's risk of death in an auto accident associated with living in one city instead of another, riskier, city (see (Krupnick and Cropper 1992)) or choosing between two bus companies with different safety records when deciding to ride a bus (Jones-Lee, Hammerton et al. 1985) . Therefore, attempts are made to ascertain WTP to reduce the chance of death by some small probability. Framing the question in this way highlights an important point: a WTP estimate for mortality risk reduction does not provide an inherent value for human life; rather it illuminates the choices and tradeoffs that individuals are willing to make and converts those choices into a value for a *statistical* life (VSL) by aggregating over many people their WTP for small changes in risk.

Calculating the implied value of health outcomes from WTP studies is usually straightforward. Using the "damage function" approach or "integrated assessment," (see below), the unit values for the different endpoints are multiplied by the expected change in the incidence of the effect, taken from physical response functions in the literature. However, it is also possible to determine total WTP without going through the step of applying values to expected outcomes.[6]

An important issue bearing on the validity of monetary valuation is its applicability to the context in which it is used. Most studies are site-specific and coverage of all possible sites and situations is impossible. Therefore, it is often necessary to transfer the results of a study that focuses on one specific situation to another study with a different location or setting of interest. This procedure is known as benefit transfer, and there are occasions when the reliability of valuation estimates can be questioned. For example, hedonic wage studies provide mortality risk reduction valuations based on accidental deaths of prime working-age individuals. It can be argued that this context is inappropriate for estimating the benefits of pollution control, where older and ill individuals are most at risk

In the area of estimating WTP for health outcomes, there is a vast literature including pronouncements from expert committees on appropriate protocols. The so-called National Oceanic and Atmospheric Administration (NOAA) Panel (Arrow, Solow et al. 1993), made up of several Nobel laureate economists, survey researchers and others, developed recommendations about how to conduct credible stated preference studies on the valuation of natural resources, recommendations that generally carry over to health valuation.[7] Major books and articles on WTP methods include (Mitchell and Carson 1989; Freeman III 2003) (Carson, Flores et al. 2001) (Carson, Hanemann et al. 1996) (Cummings, Brookshire et al. 1986) (Alberini, Krupnick et al. 2003), and (Champ, Boyle et al. 2003). In addition, a variety of computer models and modeling efforts have codified the health valuation literature. See, in particular, (EPA 1999), (Rowe and al 1995), (Farrow, Wong et al. 2001), and (European Commission 1999). We know of only one

[6] For instance, in measuring the WTP to reduce air pollution using housing price variation over space, the physical effects measure is embedded in perceptions of homebuyers and sellers about what would happen to their health if they live in homes at locations with different degrees of air pollution. Because this approach uses public perceptions of dose-response relationships rather than scientifically-based relationships, it has fallen into disuse in favor of the damage function approach.

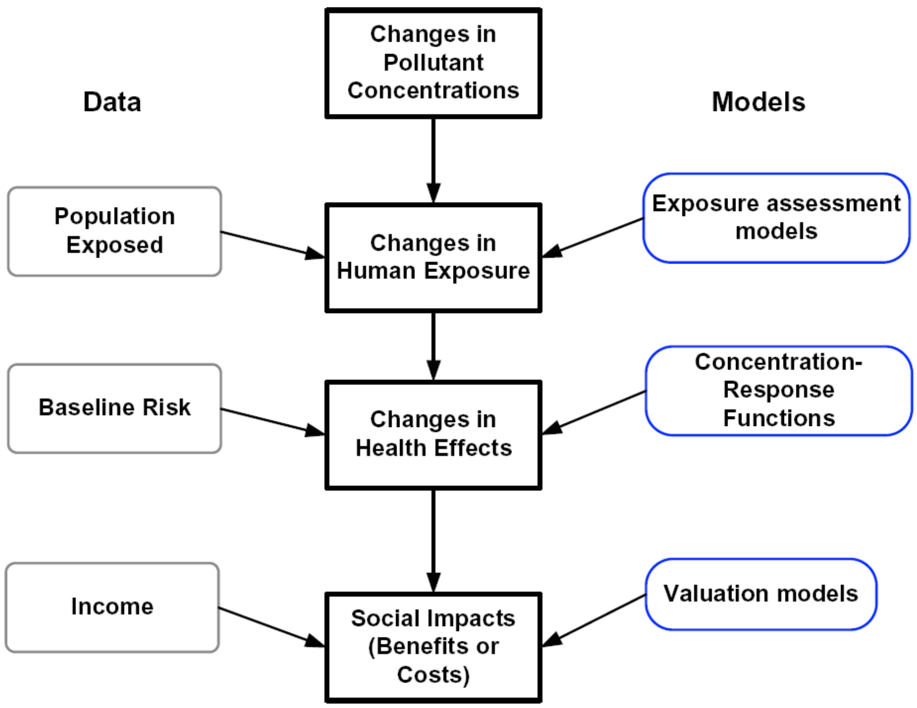
[7] The NOAA panel was convened to sort out competing claims about the credibility of CV surveys on existence value in the wake of the Exxon Valdez oil spill in Prince William Sound, Alaska.

study that has tried to estimate the WTP for mortality risk reductions in Latin America, conducted by one of the authors, in Santiago, Chile, during 1999 (Cifuentes, Prieto et al. 2000) .

I.B "Integrated Assessment" Approach

The approach taken in this study to implement the economic analysis sketched above is an example of what is known by policy analysts as "integrated assessment" using the "damage function" approach. An integrated assessment is a multidisciplinary, multi-step modeling approach to problems, in this case to the estimation of economic and physical benefits to health of air pollution improvement. The integrated assessment approach is shown in Figure I-1.

Figure I-1 Damage Function Approach



This approach involves a series of interlocked components beginning with changes in ambient air pollution concentrations and ending in societal benefits, using data and models drawn from government institutions and the academic literature. This report is organized by these components.

I.C Scope of the Study

The air quality data we use for the study are centered on particulate matter (PM-10, specifically). We note here that the study emphasizes PM-10 not just because usable data are available for this pollutant, but also because of its strong identification in problems of illness and premature mortality based on a large international epidemiology literature (Holgate, Samet et al. 1999).

There are many air pollutants that can cause health problems. The most common ones are referred to as "criteria pollutants" and include particulate matter (PM_{10} or $PM_{2.5}$), SO_2, NO_2, CO, O_3 and lead. Although all of them are known to cause health problems, the pollutants of higher concern in LAC are particulate matter and ozone, which is itself an indicator of many other oxidants present in the air.

Usually, health impact analyses consider these two pollutants, which represent two more or less independent sources of impacts. However, in this project we undertake the estimation of PM_{10} -related impacts only. This is based on the availability of data (which are seldom sufficiently available for analysis of O_3 reduction benefits).) There is a difficulty in that ozone is more heterogeneous both temporally and geographically than PM_{10}, making computations with ozone more difficult. Further, what most cities report is the number of exceedances of the ozone standard, or the maximum one hour level during a month. From that information it is not possible to compute the health effect

Two cities in which the impacts of PM an*d* O_3 *hav*e been estimated recently are Mexico City and Santiago, Chile. According to Molina and Molina (2002), the benefits from a reduction of 10% in PM_{10} and ozone levels in the Metropolitan Area of the Valley of Mexico in the year 2000 are about \$2 billion for PM_{10} and only \$200 million for ozone. [8] In Santiago, the benefits of the Decontamination Plan were assessed by one of the authors (Cifuentes, 2001) in a report for the Chilean Environmental Commission. The total benefits from $PM_{2.5}$ reductions likewise were about 10 times the benefits from ozone reductions. These figures suggest that the downward bias in our estimates from exclusion of ozone is not too large.

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[8] However they did not considered hospital admissions, which are high for ozone, in their calculations. The study by Cesar et al (2000) shows a different picture. For a 10% reduction in pollution levels, ozone benefits are 70% of those of PM_{10} when WTP is considered. When only cost of illness and human capital losses are considered, ozone benefits are 3 times those of PM_{10}. This is because most of ozone effects are hospital admissions, which account for a big fraction of COI benefits. For an scenario in which the air quality standards are attained for both pollutants, ozone benefits are 2 and 8.8 times those of $_{PM10}$ for COI and WTP values respectively .This higher

Lead from motor fuel is another serious threat to public health, but the region has already made considerable progress in reducing fuel lead levels and data on blood lead levels were not readily accessible to us[9]. We also recognize that hazardous air pollutants are present in most Latin American cities; however, there is no systematic information on the importance of these pollutants in the different cities.

This section is followed by a description of population and other baseline incidence data needed for estimating health improvements and benefits. The following section focuses on the epidemiological literature linking changes in air quality to human health. This section is followed by another on the economic health valuation literature. The remainder of the paper presents the main results and conclusions.

II. Air Quality Data in Latin American Cities

This section presents the air quality data in Latin American cities that will be used in this report to estimate the health benefits that can be obtained from reducing air pollution. There is also a brief discussion of the main sources of pollution in these cities. A significant effort has been made to identify cities with "solid" air quality data as well as other cities where the available information gives some idea as to the magnitude of the problem but is less reliable.

II.A Main Sources of Air Pollution in LAC

The urbanization process in Latin America is an ongoing process. Currently about 75% of the population of Latin America and the Caribbean live in cities (UNEP 2002). Several megacities such as Buenos Aires, Mexico City, Rio de Janeiro and Sao Paulo, each with a population of more than 10 million, are located in the region and economic growth in these urban centers has caused increases in air pollution (particularly CO, NOx, SO_2, tropospheric ozone (O_3), hydrocarbons and particulates) and associated human health impacts (UNEP, 2000).

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value is due to the fact that the percentage reductions required to attain the O3 standard are much higher than those for PM_{10}.

[9] Concentrations of lead have been reduced since most of the countries in Latin America have eliminated lead from their fuel or are in the process of doing so. In South America there are only five countries still supplying leaded fuels: Uruguay, Venezuela, Cuba, Peru and French Guinea. Also, some of their Caribbean Islands still use leaded fuel. It is believed that lead will be completely phased out in the region throughout the next decade. See for example http://www.walshcarlines.com/pdf/leadphaseoutupdate.pdf.

There are many sources that are responsible for emissions of particulates and particulate precursors, including SO_2 and NOx. Transport activity is a main source of direct and indirect pollution, especially in larger cities, but also increasingly in medium sized cities. It is estimated that over 40% of emissions of PM_{10} in Mexico City and 86% in Santiago come from the transport activity[10]. In addition, NOx emissions from transport in both cities account for more than 75% of total emissions of NO_X (O'Ryan and Larraguibel 2000). On the other hand emissions from fixed sources only account for 7% and 14% in Santiago (for PM_{10} and NO_X) and around 15% and 12% in Mexico City. However, the lack of knowledge, even in these two more advanced countries in terms of air pollution control is significant. For example in Santiago the characterization of particulates obtained from filters shows a different mix for the sources responsible for PM_{10}: 49% mobile sources, 29% for fixed sources including industry and residential and 22% for area sources (CONAMA RM, 2001).

Direct emissions from vehicles as well as suspended particles from dust, both on paved and unpaved roads, are responsible for an important amount of air pollution. Fuel quality - particularly sulfur content in gasoline and diesel fuel- is a key factor that determines the amount of SO2 emissions, which contribute to PM_{10} when converted in the air to sulfates. As a comparison sulfur contents in diesel fuel in Brazilian cities reach up to 1000 ppm, while in Mexico City these are currently 500 ppm and Santiago, Chile these have been reduced from 500 to 300 ppm in 2001 and to 50 ppm in mid 2004. For comparison, the US and Canada now limit the sulfur content to 500 ppm, while most European countries require 50 ppm, but some (Denmark, Sweden) limit it to 15 ppm) (Walsh 2005).

Old car, truck and bus fleets in Latin America are an important factor. Whereas on average vehicle turnover in the US is relatively rapid, it is not uncommon for cars in cities of Latin America to be 10 or even 20 and more years old. Another related factor is the inadequate maintenance of engines. In many cities, the main source of pollution is old diesel-fuel buses and trucks with poor maintenance, which contribute heavily towards total emissions[11]. Excess circulation of buses in off-peak hours due to the need to finance the fixed costs of small bus-owners adds significantly to emissions in some cities. Finally the last source of air pollution from

[10] This latter number includes direct emissions from combustion and indirect emissions from paved and unpaved roads.

[11] For example diesel buses and trucks in Santiago contribute up 46% of total direct emissions of particulates (not including resuspended particles) and 54% of emissions of NOx (CONAMA. 2002).

transport is related to driving patterns and congestion. Poor driving patterns (e.g., excess acceleration and deceleration) can increase total emissions of different pollutants significantly. A recent study for Santiago showed that improving driving conditions in public buses can reduce emissions of CO, VOCs, NOx and particulates in over 25%. Additional studies in Argentina and Mexico show similar results.

The second main source of pollution in Latin America comes from industrial activities. In several cities, industrial activity is still an important source of air pollution emissions. However several larger cities have attacked the problem by imposing and enforcing emission standards for industrial sources. Such is the case for example, for Santiago and Mexico City as well as in Quito and Bogotá. However there are still some cities with heavy industrial air pollution such as Cubatao in Brazil.

In certain specific areas the air pollution problem is not related to vehicles or industrial activity, but rather to residential use of fuel wood for cooking and/or heating as in Temuco and other mid sized cities in the south of Chile and some Central American countries; forest fires such as in Central America, or even a volcano eruptions as in Quito, Ecuador in 1999 (UNEP 2002). Unfavorable topographic and meteorological conditions in some cities aggravate the impact of air pollution: the Valley of Mexico obstructs the dispersal of pollutants from its metropolitan area as do the hills surrounding Santiago (ECLAC 2000). This is perhaps more of a problem for ozone than PM_{10}.

In summary, most PM_{10} pollution problems in Latin American cities can be related to the transport sector. However, a few cities do not follow this pattern and the main sources of high PM-10 concentrations are either industrial activity or residential use of fuel-wood. Since growth in income for developing countries in LAC is expected, it is very likely that vehicle-related emissions will increase significantly as more people have access to cars.

II.B The challenge of finding air quality data

Compiling air quality data in Latin America requires a significant effort. A first problem is that the existing data are not readily available and the quality of the data is usually not known except by a few local experts. Consequently, where the information exists, often a visit or a contact with a local official is required to obtain it and assess its quality. On other occasions the information does not exist at all or is outdated.

Continuity of the information is another problem and the task of building a time series of acceptable quality is very difficult, with few exceptions. Regular air monitoring networks are expensive to set up, operate and maintain. For example, the monitoring network in Santiago cost US$ 2 million to implement and requires each year approximately US$ 0.5 million to operate and maintain. As a result in many cities there are air quality studies for only one or two short periods. This makes it difficult to establish whether the information obtained is of good quality and representative enough of the state of the environment. In many cases different methodologies are used to measure air quality in different studies that may not be comparable.

Access to the available information is another problem. Recently the use of information technologies, especially the Internet, has allowed part of the data collection process to be speeded up. Nevertheless, the process is still slow and complicated. Information technologies have not been taken advantage of to produce comparable data sets for different Latin American cities that could make the search for information less cumbersome and uncertain. Another issue is that on many occasions the information is not publicly released –so it may exist but not be accessible- or it may not be released to the extent needed for credible research.

II.C Air Quality in Latin American Cities

Based on expert judgment the air quality situation is presented for 21 cities with reliable information (type A cities), and for 18 cities with data that are more uncertain but that are expected to reflect typical annual averages, for a total of 39 cities.

The data are the result of a combination of readily available data from internet, communications with local experts in Latin American cities and expert opinion on the quality of the data from the research team. An effort has been made to include all major cities for which experts concur there are or could be air pollution problems and to ensure that the information for the key cities considered is of reasonable quality. The numbers presented may not include a city for which there is acceptable information, simply because the information was not readily accessible, however these cities should be few. Similarly, the quality of the information in all cities is not the same, so cities with more reliable information have been grouped by data quality based on expert judgment[12].

[12] In general type B cities lack a monthly data.

Several countries including Brazil, Mexico, Colombia and Chile have regular monitoring programs that have followed USEPA guidelines. There is local expertise and the data from these cities can be considered of good quality. This information together with that of Panama City and Kingston, Jamaica for 1997-2003, is included in Table II-2 and comprises 21 cities with data that can be considered of good quality[13]. The first two columns identify the country and city for which data were found. The next two columns show the average and monthly maximum of PM_{10} concentrations in each city except for Santa Marta and Panama City where TSP was considered.

Clearly, air quality is an issue in both large and small cities. Almost all cities, except four small Brazilian cities (Canoas, Sao Jose, Sorocaba and Vitorio), have annual averages over 40 $\mu g/m^3$, and higher monthly maximum levels. This suggests that probably all cities would benefit significantly from reducing air pollution. Santiago has the worst PM_{10} pollution problem, but Ciudad Juarez, Monterrey and Mexico City also have serious episodes at some time of the year. Cubatao, Bogotá, Guadalajara, Toluca also appear to have problems since their maximum monthly average is over 75 $\mu g/m^3$.

[13] Panama City has monthly data for a specific period but not a regular monitoring program. Similarly, Kingston had a program in 1997 in which a continuous monitoring network was undertaken based on hourly measurements in several sites during a four month period.

Table II-1 PM_{10} concentrations in Type A Cities with Air Quality Data Available for 1997-2003

Country	City	Average of the period ($\mu g/m^3$)	Monthly Maximum ($\mu g/m^3$)
Brazil	Campinas	42.9	69.0
	Canoas	25.4	41.9
	Cubatao	65.3	90.0
	Porto Alegre	44.8	53.8
	Sao Jose	34.2	49.4
	Sao Paulo	49.0	72.2
	Sorocaba	30.5	47.3
	Vitorio	27.8	31.9
Chile	Calama	61.4	71.8
	Santiago	82.0	117.7
	Temuco	43.8	68.1
Colombia	Bogotá	59.3	77.4
	Cali	43.4	45.9
Jamaica	Kingston [b]	69.0	N.A.
Mexico	Guadalajara	58.0	79.2
	Juarez	65.9	103.3
	Mexico City	60.2	94.6
	Monterrey	67.0	112.0
	Puebla	56.7	74.8
	Valle de Toluca	48.6	80.0
Panama	Panama City [a]	77.1	93.2

[a] The values for Panama City in Panama correspond to TSP.

[b] The value for Kingston is from hourly measurements during 4 months in 1997.

Table II-2 presents additional air pollution data for 18 cities where only annual data were found readily available. The information is less reliable; however, we feel that the numbers give good insights as to the annual average air quality situation in these cities. We label these type B cities. Both TSP and PM_{10} concentrations are very high. Lima and Quito are of particular concern given the high exposed population. The value for Buenos Aires also appears high; however this does not seem to reflect the true level of pollution, which is probably lower, according to expert opinion. However other Central American cities also have serious problems.

Table II-2 PM_{10} or TSP concentrations in Type B Cities

Country	City	Period [a]	PM10 Annual Average (μg/m³)	TSP Annual Average (μg/m³)
Argentina	Buenos Aires	1997-1998		188.5
	Cordoba	1987-1992		154
	Mendoza	1997-1998		31.2
Brazil	Curitiba	2000-2001		51
	D. Caxias	1986-1993		115.6
	Itaguai	1989-1996		35.6
	Rio De Janeiro	1986-1996		128.1
	S.J. Meriti	1986-1996		182.4
Costa Rica	Heredia[a]	1996	76.5	228.3
	San Jose[a]	1996-1999	53	200
Ecuador	Guayaquil[a]	1994-1995		120.7
	Quito	1994-1998	59.5	200.1
El Salvador	San Salvador[a]	1996-1999	62.7	189.4
Honduras	Tegucigalpa[a]	1994-1999	79.4	452.7
Nicaragua	Managua[a]	1996-1999	60.9	313.8
Peru	Lima[a]	1999	146.4	165.8
Uruguay	Montevideo	1998-1999		253.3
Venezuela	Caracas	1986-1995		67.8

[a] The period for measurements of PM_{10} and TSP is not necessarily the same. For example PM_{10} in Lima was measured for 1999 whereas TSP was measured between 2000 and 2002. For Heredia TSP was measured between 1996 and 1999, while San Jose was measured for 1993-1999: Quito's data for TSP is for 1994-1998. Finally in Tegucigalpa TSP is for 1994-1999 and PM_{10} for 1995-1999.

III. Other baseline data for the integrated assessment

This section presents demographic and other baseline data necessary for evaluating the economic impact in changes in air quality. First, the exposed population to pollution is presented. The next section includes income data and other economic information specific to the cities under study. Finally, relevant health information is presented.

III.A Population Data

There are several issues here. First, information at the city level is the appropriate degree of spatial detail. Yet, such information is not generally available. This problem was particularly significant for population (see below). In order to find the population and age distribution for the cities it is necessary to use the information from the Census of each country. The information from each Census gives a good idea for the population in the district, commune or municipality, wherever it has been measured. However, not all countries report the information at the required disaggregated level. In addition, some estimates of the population are quite old. For example, Colombia's last census was in 1993, and estimations of population have been built from this information.

Second, information on the age distribution is readily available only at the country level. Other countries have more recent Census information (Chile 2002, Brazil 2000, Mexico 2000, Panama 2000, etc.), and therefore the information is more reliable. Although in the case of Chile we had the population of each municipality by age group, in many cases this is directly available only at the regional level. In that case, we used the age structure at the most detailed level available (country or region) and then applied it to the city. When there were no data for the year of analysis, the most recent estimate was adjusted using a population growth rate estimated from the available data.

A third issue is defining the geographic area of the exposed population -- how many people in what areas are affected by the air quality measurements being considered. The exposed population of the city usually does not correspond to the political boundaries of the districts. For this project the general assumption is that the exposed population is the one living in the *metropolitan areas* of each city. For example, the Santiago Metropolitan Area includes the Province of Santiago with 34 municipalities plus two other municipalities (San Bernardo and

Puente Alto). Therefore, in order to consider the whole population it was necessary to add these two municipalities. Similar efforts were undertaken for the other cities.

A related issue is determining the air quality to which the exposed population is subject to. First, for some cities there are different monitoring stations registering very different concentrations. For example, in Sao Paulo 23 monitoring points were identified that reported PM_{10} concentrations ranging from 29 to 67 micrograms per cubic meter in October 2003. In Santiago, Mexico and Bogotá these differences are also substantial. Moreover, the population tends to move around so the population exposed to air pollution in a given receptor location may be very different than the one living in the same area. We assumed that all the population of the Metropolitan Area is exposed to the average of the air quality measurements from all monitoring stations[14],[15].

III.B Income data

Another group of information required to perform the benefit estimation is per capita income by city, put in common units by using conversions based on purchasing power parity (PPP). Per capita income information is normally not directly available and therefore some assumptions are required. Some countries report household and per capita income through their socioeconomic (Chile) or income/expenditure (Mexico) surveys or directly through the information from the census, as in Panama. However these are not always available or statistically representative for every city or district in the country. In other places this information is not available and other sources must be used.

For our analysis, data for regional or state Gross Domestic Product (GDP) per capita were obtained for some countries, and are used as a proxy for personal income. The United Nations' Economic Commission for Latin America and the Caribbean (ECLAC) has a database of per capita income and data for some cities were obtained from this source. Finally, for a few Central American cities for which there were no data at the city level, the country's per capita Gross National Income (GNI) from the World Bank had to be used.

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[14] Since this assumption is usually used in the epidemiologic studies to characterize the exposure of the population, it is not clear than a better characterization of exposure will improve the precision of the estimates of the effects. To the contrary, it might even worsen it.

Purchasing Power Parity income (PPPI) is available from the World Bank only at the country level. Since income varies for cities of the same country, the PPPI was calculated for each city by adjusting it in proportion to the ratio of per capita income in the city to the country, as follows:

$$PPPI_{city} = PPPI_{country} \frac{PCI_{city}}{PCI_{country}}$$

Table III-1 shows the population and income data for the cities and for the countries.

[15] An exception is Rio de Janeiro where there are monitoring stations in specific localities that represent better the air quality conditions.

Table III-1 Population and Per capita Income by city for the year 2000

Country	City	Population	Per capita Income (US$/p)	Purchasing Power Parity Income PPPI (*) (US$/p)	Source (*)
Argentina	Buenos Aires	8,680,000	4,930	12,000	INDEC: Censo 2001
	Cordoba	1,368,000	3,830	9,370	INDEC: Censo 2001
	Mendoza	846,900	3,250	7,940	INDEC: Censo 2001
Brazil	Campinas	969,400	5,080	12,900	IGBE: Censo 2000
	Canoas	306,100	9,550	24,300	IGBE: Censo 2000
	Caxias	775,500	4,380	11,100	IGBE: Censo 2000
	Cubatao	108,300	5,080	12,900	IGBE: Censo 2000
	Curitiba	1,587,000	7,310	18,600	IGBE: Censo 2000
	Itaguai	82,000	4,380	11,100	IGBE: Censo 2000
	Porto Alegre	1,361,000	3,340	8,510	IGBE: Censo 2000
	Rio De Janeiro	5,858,000	4,380	11,100	IGBE: Censo 2000
	Sao Joao De Meriti	449,500	4,380	11,100	IGBE: Censo 2000
	Sao Jose Do Campos	468,300	5,080	12,900	IGBE: Censo 2000
	Sao Paulo	10,430,000	4,370	11,100	IGBE: Censo 2000
	Sorocaba	493,500	5,080	12,900	IGBE: Censo 2000
	Vitoria	292,300	3,350	8,530	IGBE: Censo 2000
Chile	Calama	138,400	3,320	7,160	IGBE: Censo 2000
	Santiago	5,408,000	4,920	10,600	IGBE: Censo 2000
	Temuco	245,300	4,800	10,300	INE: Censo 2002
Colombia	Bogota	6,866,000	3,370	10,800	INE: Censo 2002
	Cali	4,318,000	1,960	6,280	INE: Censo 2002
Costa Rica	Heredia	98,500	1,620	3,260	DANE
	San Jose	309,700	2,680	5,410	DANE
Ecuador	Guayaquil	1,985,000	2,620	5,650	DANE
	Quito	1,399,000	2,480	5,340	INEc: Censo 2000
El Salvador	San Salvador	479,600	2,080	4,570	INEc: Censo 2000
Honduras	Tegucigalpa	850,200	395	1,050	INEc: Censo 2001
	Kingston	655,000	2,820	3,550	INEc: Censo 2001
Mexico	Guadalajara	3,772,000	3,060	4,420	Ministerio De Economía
	Juarez	1,219,000	5,910	8,540	INE: Censo 2001
	Mexico City	19,220,000	7,880	11,400	INEgi: Censo 2000
	Monterrey	3,280,000	5,910	8,540	INEgi: Censo 2000
	Puebla	1,272,000	5,910	8,540	INEgi: Censo 2000
	Valle De Toluca	1,253,000	3,000	4,330	INEgi: Censo 2000
Nicaragua	Managua	864,200	420	420	INEgi: Censo 2000
Panama	Panama City	825,300	1,950	2,850	INEc: Censo 1995, Proyeccion 2003
Perú	Lima	7,501,000	2,210	5,180	Dirección De Estadísticas Y Censos: Censo 2000
Uruguay	Montevideo	1,381,000	4,360	12,000	INEi: Censo 1993, Proyección 2000
Venezuela	Caracas	1,836,000	5,410	6,720	INE: Censo 1996, Proyección 2003

Notes (*) PPPI values imputed for each city based on the country value and the ratio of PCI of the city to the country (when there was no PCI value at the city level, the country value was used)

III.C Health Data

Health status information is needed for the calculation of most types of health effects, because the concentration-response functions provide a relative change in the baseline incidence rate per change in pollution. Mortality rates by age groups at the country level are generally available. Table III-2 shows such data, obtained from the WHO mortality database for 1999 for most of the countries analyzed. Data at the city level is harder to come by. Rates do not vary significantly from year to year, so we used the rates for 1999, and, in some cases, for previous years, as indicated in the tables.

Compared to the more mature economies, the rates are low, reflecting the high fraction of children to adults in most Latin American countries. Whereas the U.S. crude mortality rate is around 800 per 100,000, most Latin American countries have rates under 600, with some as low as 300 per 100,000.

Table III-2 Crude Non accidental Mortality Rate by Country for 1999 (cases per year per 100.000 people)

Country	All Population	Children 0-17 yrs	Adult 18-64 yrs	Elder (65+)	Year of data
Argentina	724	104	309	5,344	2001
Brazil	477	125	307	5,111	2000
Chile	506	63	213	5,195	1999
Colombia	374	116	205	4,489	1999
Costa Rica	359	72	184	4,351	2002
Ecuador	391	147	250	4,459	2000
El Salvador	358	86	263	3,905	1999
Honduras	472				
Jamaica	580				
Mexico	379	103	229	4,604	2001
Nicaragua	342	140	269	4,964	2000
Panama	500				
Peru	303	93	194	3,621	2000
Uruguay	858	84	317	5,119	2000
Venezuela	381	124	251	4,575	2000
USA	800	46	262	5,085	2000

Sources: rates computed using the death data from the WHO mortality database (http://www3.who.int/whosis/menu.cfm?path=mort) and the population from the same source. When population was not available, it was projected from the available data assuming the same trend.

Incidence rates are also needed for morbidity endpoints. These data are much more difficult to obtain. We had to rely on published studies of health impacts to obtain it for some of the cities. When such data was not available for a city, we relied on incidence rates from the literature, even though they are mostly from the US. In summary, despite the fact that information technologies have improved the access to information, it can be observed that the task of obtaining good quality information for Latin America is still difficult.

IV. Quantification of Health Impacts

IV.A Basis for the quantification of health impacts

In the literature, health effects are termed "endpoints." Endpoints can be classified into four categories: premature mortality; medical actions, such as hospitalizations; illness or disease; and restrictions in activity (including days of lost work). They can also be classified by the nature of their effects, chronic or acute. Premature mortality and medical actions endpoints can also be classified by their causes, according to the International Classification of Diseases 9th Revision (ICD9). Due to this classification, some of the endpoints overlap, and care should be taken when adding them, so as to avoid double counting. For example, pneumonia hospital admissions (ICD9 codes 480 through 487) are included within respiratory hospital admissions (ICD9 460-519); therefore, they can't be added together. The same kind of inclusion occurs in the "restriction of activity" endpoints. Work lost days (WLD) are included in Restricted Activity Days (RADs), which in turn are included in Minor Restricted Activity Days (MRADs)[16].

All the endpoints typically included in quantification analyses are represented in Table IV-1. Also on the table are the cities and countries from which the concentration-response studies were drawn. As the table shows, many, but not all, of these endpoints have been studied in Latin American cities. Rather than ignoring these subsidiary endpoints, we treat them as separate endpoints for calculation purposes and then net them out of the more inclusive endpoint cases or values, as appropriate. In a next section we explain how this aggregation is performed.

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[16] By increasing degree of severity degree these endpoints are MRAD, RAD, WLD, so a WLD will be counted amongst the RADs and a RAD will also be counted in the MRADs,

Table IV-1 Health Endpoints Considered in the Analysis

Exposure	Type of Endpoint		Endpoint (specific cause)	City/Country providing C-R functions
Long-term	Premature Mortality		All cause	USA
			Cardiopulmonary	USA
			Lung cancer	USA
	Illness or Disease		Chronic Bronchitis	USA
Short-term	Premature Mortality		All cause mortality	Several LA cities / USA
			Respiratory causes	USA
			CVD causes	USA
	Medical Actions	Hospital Admissions	Cardiovascular disease (ICD9 390-429)	USA
			Asthma	USA
			Dysrhytmias (ICD9 427)	USA
			Respiratory Causes (ICD9 460-519)	Sao Paulo/USA
			Pneumonia (ICD9 480-487)	Sao Paulo/USA
		Emergency Room Visits	Asthma (ICD9 493)	Sao Paulo
			Cardiovascular disease	Sao Paulo
			Ischemic Heart Disease	USA
			Respiratory Causes	Santiago
			Pneumonia and Influenza	USA
			Pneumonia (ICD9 480-486)	Santiago
			Lower-RSP	Santiago
			Upper RSP symptoms (ICD9 460, 465, 487)	Santiago
		Medical Visits	Asthma (ICD9 493)	Juarez
	Illness or Disease		Asthma Attacks	USA
			Acute Bronchitis	USA
	Days with Restriction in Activity		Work Loss Days (WLD)	USA
			Restricted Activity Days (RAD)	USA
			Minor Restricted Activity Days (MRAD)	USA
			Shortness of Breath Days	USA

The quantification of health impacts for these endpoints due to air pollution improvements is based on the results of epidemiological studies. One of the aims of epidemiological studies is to find the ”concentration-response” (C-R) relationships, which relate a response observed in the population (for example, the incidence of acute bronchitis) to the concentration of the risk agent to which the population has been subjected – in our case PM. These studies have found statistically significant associations between the incidence of an effect and the level of air pollution, while controlling for potential confounding factors.

We distinguish between two major types of epidemiological studies – time-series and cohort. Most of the recent epidemiological studies are time-series studies, which are based on the analysis of the relationship of daily changes in the incidence of an effect (for example, the number of hospitalizations for respiratory causes in any given day) with some measure of daily air pollution levels. These can be the same or previous days levels, or the average of the levels for some number of days before the event under study (for example, the average of the previous three days). Confounders like ambient temperature, humidity, seasonal effects and the presence of epidemics (like the flu epidemic) are controlled for in the analysis. Other potential confounders, like the smoking habits of the population, are not supposed to change from day to day in association with air pollution.

Due to its design, this type of study can only identify the effects that spikes in air pollution have on health. They cannot pick up the cumulative effect of exposures over many years, for instance. Nevertheless, these types of studies have been conducted all over the world, with populations of different characteristics, health services provision, and meteorology (all factors that effect the response of the population to air pollution). The result is a broad consensus that PM-10 has significant effects on all of the endpoints noted in Table IV-1, although there are other endpoints, (like the inception of asthma) where there is still not enough information.

Perhaps the most persuasive epidemiological studies, although far fewer in number, are the cohort studies. This type of study follows a group of individuals (a cohort) for a relatively long period of time (several years), recording the occurrence of health effects. The most important characteristics of the individuals (body weight, smoking status, etc) can be assessed periodically, so confounders are controlled by accounting for individual characteristics (such as smoking history) Ambient characteristics (meteorology, air pollution) can be obtained from monitors close to the individual's residence. This kind of study is capable of assessing long-term effects of air pollution on health, which, depending on design, may incorporate the short-term effects picked up in time series studies. Because they are quite expensive to conduct, since they required a long campaign of data collection, few of these studies have been done, all of them in the US. Nevertheless, the cohort studies are those most often relied on in the U.S. in cost-benefit analyses of air pollution regulations and are generally believed to be the most reliable and comprehensive assessments of the long-term effects of PM-10 on health.

Details of Estimating Health Effects

Most of the C-R functions are of the relative risk type, i.e., they estimate the change in effects relative to a baseline, which is usually the observed incidence of effects in the population of analysis. The change in effects that a given population group experiences due to a change in pollutant concentrations is therefore given as:

$$\Delta E_{ij}^{k} = f(Pop_{j}^{k}, IR_{ij}, \beta_{ij}^{k}, \Delta C^{k})$$

where

- Pop_j^k is the number of people of group *j* that is exposed to the pollutant *k*
- IR_{ij} is the incidence of endpoint *i* in population *j*
- β_{ij}^k is the unit risk of endpoint *i* in subpopulation *j* due to pollutant *k*
- ΔC^k is the change in concentration of pollutant *k*

This can be rewritten as

$$\Delta E_{ij}^k = f\left[\left(Pop_j^k \cdot IF_{ij}^k(,IR_{ij},\beta_{ij}^k)\right),\Delta C^k\right]$$

where $IF_{ij}^k(IR_{ij},\beta_{ij}^k)$ is the impact factor of endpoint *i* in population group *j* due to pollution *k*, which incorporates the unit risk β_j^j and the incidence rate IR_i^j of the effect.

It is important to note that effects are computed for a set of *endpoints-subpopulation-pollutant* (*i*,*j*,*k*) , so before quantifying them we need to define:

the endpoints to be included in the analysis (i)

the subpopulations into which the population is to be separated. (j)

the pollutants included in the analysis (k)

Of course, the three decisions are related, since the impact of air pollution needs to have been estimated before through epidemiological studies. Once pollutants are defined, we need to define the endpoints, and that decision will condition our consideration of subpopulations.[17] For example, for acute bronchitis, the studies that have shown an association with PM_{10} have been conducted only in children age 8-12 years.

Table IV-2 provides the number of studies for each endpoint and city in Latin America. Note that Mexico City has been the most studied city in Latin America, with 10 studies to estimate concentration-response functions, seven of which are for premature mortality. In total our analysis uses up to 21 independent concentration-response functions taken from Latin American

[17] There are many ways to disaggregate the population into different groups: by age, by gender, by health status, by educational level, and by socioeconomic status. All of these divisions have been shown, at least in one study in one place, to have different response to air pollution. The main division however is by age groups: Children, Adults, and Elderly. That is the division we use in this work.

efforts. These Latin American studies were obtained from a systematic review of the published and unpublished literature, as well as the authors calling on their extensive academic network. These studies are supplemented by a large number of studies from the U.S. and elsewhere.

Table IV-2 Number of health studies conducted in Latin American cities, by endpoint type

City	Premature Mortality	Morbidity		
		Hospital admissions	Emergency Room Visits	Child Medical Visits
Mexico City	9		2 (1)	1 (2)
Sao Paulo	4	3	1	
Santiago	3		1	1 (3)
Total	16	3	4	2

Notes
(1) One study is for Ciudad Juarez
(2) Child Medical Visits LRS
(3) Child Medical Visits LRS, URS

In the next sections we assess the results of these studies.

IV.B Mortality impacts

The most severe impact is premature mortality. Also, it is the most studied and the most important in terms of public welfare. Exposure to air pollution affects mortality rates in two ways: an increase in pollution can have a *short-term* effect, increasing mortality over the days following a spike in pollution. This is the kind of effect observed in the 1950's and 60's in London, when a sharp increase in pollution lead to an increase of mortality rates in subsequent days (Bell and Davis 2001). These effects are captured by the time-series studies noted above. But constant exposure to air pollution can also have long-term effects: these are referred to as "chronic" effects. These are the kind of effects uncovered by cohort studies. Cohort studies also capture short-term effects.

IV.B.1 Time-Series Studies

By far, the most studied endpoint in Latin America is premature mortality associated with short-term exposure to increased air pollution, i.e. changes in exposure in the previous days of the death. All the studies are of the same type -- daily time series— which relate the average number of deaths in a day with the air pollution levels in previous days.

Concentrations of ambient air pollutants, especially those that come from the same sources, are usually highly correlated. Some studies attempt to separate the effects of different pollutants, by simultaneously including them in the regression models. Since we are estimating the effects for PM_{10}, whenever possible we consider studies that include many pollutants simultaneously, which is this case was only feasible for all ages. For elder, there were few studies with co-pollutants, so we did not include them . Failing to control for ozone, for instance, would probably lead to an overestimation of the PM effects, while controlling for more pollutants may result in an underestimation, as some of the studies show.[18]

Since there are many studies of this endpoint, we conducted a "meta-analysis" – a statistical analysis of multiple studies, where the results from each study are themselves treated as data and conclusions about statistical relationships are made from considering these data across many studies. Our meta-analysis included all the available studies in Latin America on each of the endpoints where such studies existed. Studies were grouped by age groups (all ages, elderly (>=65 yrs), and infants (less than 1 year old)) and by whether they considered any co-pollutants in the statistical model. Summary estimates were obtained using a "fixed effects" model, in which it is assumed that the results in each study are independent observations of the same underlying process that differ only due to a statistical error, and using a "random effects" model, in which it is assumed that the effect in each study has a fixed component plus a random component, different for each study. Table IV-3 presents the summary estimates for the meta-analyses of premature mortality coefficients for all ages and for the elderly.

[18] With some notable exceptions like Castillejos 2000.

Table IV-3 Summary estimates from the Meta-analysis of Latin-American studies of the effects of PM_{10} on All Cause Mortality

Age group	City	Co-Pollutant	Number of studies	Metric	% Increase per 10 ug/m3 PM10	(95% CI)	References
All Ages							
	All	**none**	**6**	FE	**0.41%**	(0.32% - 0.51%)	Borja-Aburto 1997, O'Neill 2004, Castillejos 2000, Cifuentes 2000, Ostro 1996, Gouveia 2000b
				RE	**0.61%**	(0.26% - 0.97%)	
		none	**4**	FE	**0.70%**	(0.57% - 0.82%)	Borja-Aburto 1997, Castillejos 2000, Cifuentes 2000, Ostro 1996
				RE	**0.87%**	(0.55% - 1.19%)	
		O3, SO2; O3	**4**	FE	**0.43%**	(0.33% - 0.54%)	Borja-Aburto 1997, Castillejos 2000, Cifuentes 2000, Ostro 1996
				RE	**0.91%**	(0.38% - 1.44%)	
	Mexico City	**none**	**3**	FE	**0.24%**	(0.09% - 0.38%)	Borja-Aburto 1997, O'Neill 2004-b, Castillejos 2000
				RE	**0.89%**	-(0.05% - 1.85%)	
		O3, SO2; O3	**2**	FE	**1.35%**	(0.89% - 1.82%)	Borja-Aburto 1997, Castillejos 2000
				RE	**1.37%**	(0.85% - 1.89%)	
	Santiago	**none**	**2**	FE	**0.63%**	(0.49% - 0.76%)	Cifuentes 2000, Ostro 1996
				RE	**0.64%**	(0.47% - 0.80%)	
		O3	**2**	FE	**0.38%**	(0.27% - 0.49%)	Cifuentes 2000, Ostro 1996
				RE	**0.55%**	(0.03% - 1.07%)	
Elder 65+ yr							
	All	**None**	**5**	FE	**0.66%**	(0.51% - 0.81%)	Castillejos 2000, Ostro 1996, Sanhueza 1998, Gouveia 2000b, Saldiva 1995
				RE	**0.83%**	(0.48% - 1.17%)	
		O3, SO2; O3	**3**	FE	**0.56%**	(0.37% - 0.75%)	Borja-Aburto 1997, Castillejos 2000, Sanhueza 1998
				RE	**1.00%**	(0.24% - 1.77%)	
	México City	**O3, SO2; O3**	**2**	FE	**1.35%**	(0.76% - 1.95%)	Borja-Aburto 1997, Castillejos 2000
				RE	**1.35%**	(0.76% - 1.95%)	
	Santiago	**None**	**2**	FE	**0.61%**	(0.44% - 0.78%)	Ostro 1996, Sanhueza 1998
				RE	**0.69%**	(0.30% - 1.08%)	
	Sao Paulo	**none**	**2**	FE	**0.71%**	(0.37% - 1.06%)	Gouveia 2000b, Saldiva 1995
				RE	**0.81%**	(0.13% - 1.51%)	
Infant < 18yr							
	All	**None**	**3**	FE	**2.73%**	(1.55% - 3.92%)	Loomis 1999, Linn 2000, Nishioka 2004
				RE	**2.94%**	(1.35% - 4.56%)	
	Sao Paulo	**None**	**2**	FE	**2.37%**	(1.05% - 3.72%)	Linn 2000, Nishioka 2004
				RE	**2.59%**	(0.54% - 4.69%)	
		O3, SO2; O3	**2**	FE	**3.20%**	(1.29% - 5.16%)	Loomis 1999, Nishioka 2004
				RE	**3.20%**	(1.29% - 5.16%)	

Note: FE = Fixed effects estimate, RE= Random Effects Estimate. Mid estimates shown in bold, 95% Confidence interval (percentile 2.5 to percentile 97.5 is shown in parenthesis)

The table shows that in almost all cases there is heterogeneity of impacts across cities that might be due to several factors. Although all studies were conducted in urban areas with a population over 5 million, cultural, socioeconomic, and demographic differences may influence the susceptibility of the population. Population exposure may also vary from city to city since some determinants of exposure , like concentration patterns and population mobility, might be different. Data quality differences between cities may be another source of heterogeneity in the studies. There is probably no quality problems in the meteorological data used for confounding control, but there might be more variation in the way air pollution is measured and how health data are colleted. Potential differences in diagnosis, recording, and reporting of health outcome data may also introduce heterogeneity. Finally, although statistical methods used are similar (all studies used Poisson regression), the way in which each research team adjusted for meteorological and temporal factors may produce a difference. Since we have at most four cities in any case, it is impossible to estimate the influence of each of these factors on the risk coefficients.

For our analysis we use the random effects estimates. The summary estimate for all ages, all cities yields an increase in mortality risk of 0.61% (0.26-0.97%)[19] for an increase of 10 $\mu g/m^3$ of PM_{10}[20],[21]. Surprisingly, this risk increases to 0.91% (0.38-1.44%) when co-pollutants like O_3 and SO_2 are included in the statistical models. However, part of this increase occurs because only 4 out of the 6 studies considered a co-pollutant; and for them the risk estimate without co-pollutants is 0.87 (0.55-1.19)%. For the fixed effects model, the risk actually decreased from 0.70 (0.57-0.82)% to 0.43 (0.33-0.54)%. For the elderly, the situation is similar: the risk increases from to 0.83(0.48-1.17)% to 1.00(0.24-1.77)%. In this case we cannot compare outcomes of the studies, since there is only one study that has both estimates. As in the All ages case, we choose to use the "no co-pollutant" estimate. This situation, in which the risk increases when a co-pollutant is considered in the model, appears in other cases too. Since we do not want to overestimate the effects, in those cases we choose to use so we use the estimates with no co-pollutants.

The next table shows the estimates selected for each age group for all cities pooled together, and for specific cities that had more than 2 estimates. As it is clear from the figure, the results are

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[19] The first number is the mid estimate, while the parenthesis shows the 95% Confidence interval (percentile 2.5 to percentile 97.5).

[20] This means that for each 10 $\mu g/m^3$ increase [decrease] in PM_{10} concentration, the number of deaths increases [decreases] 0.61%. This relative risk change is applied to the expected number of deaths to obtain the change in actual deaths associated to the change in PM_{10} concentrations.

[21] This means that for each 10 $\mu g/m^3$ increase [decrease] in PM_{10} concentration, the number of deaths increases [decreases] 0.61%. This relative risk change is applied to the expected number of deaths to obtain the change in actual deaths associated to the change in PM_{10} concentrations.

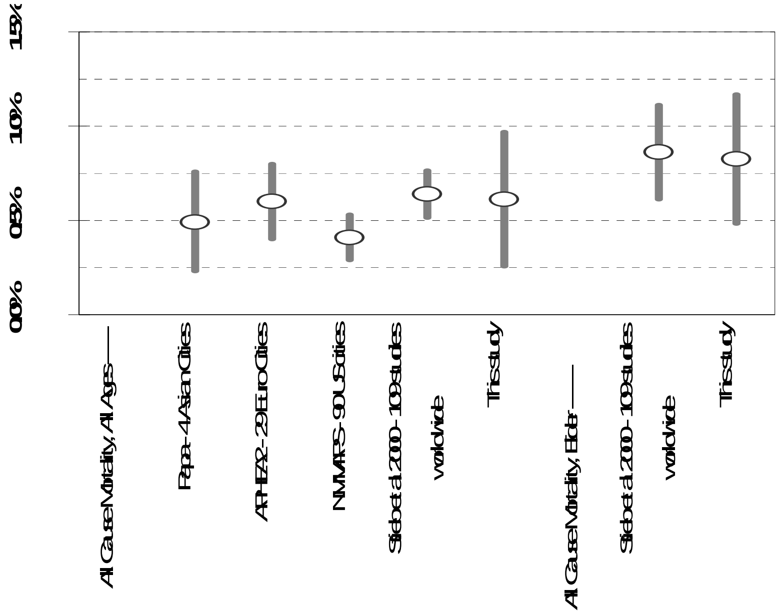
similar for all cities, except for elders in Mexico City, that have a much higher risk than the other cities.

Table IV-4 Selected estimates of the effects of PM_{10} on All Cause Mortality for each city

Age group	City	Co-Pollutant	% Increase per 10 ug/m3 PM10		n	Studies considered
All						
	All Cities	None	0.61%	(0.26% - 0.97%)	**6**	Borja-Aburto 1997, O'Neill 2004, Castillejos 2000, Cifuentes 2000, Ostro 1996, Gouveia 2000b
	Mexico City	None	0.89%	-(0.05% - 1.85%)	**2**	Borja-Aburto 1997, Castillejos 2000, O'Neil 2004
	Santiago	O3	0.55%	(0.03% - 1.07%)	**2**	Cifuentes 2000, Ostro 1996
Elder						
	All Cities	None	0.83%	(0.48% - 1.17%)	**5**	Castillejos 2000, Ostro 1996, Sanhueza 1998, Gouveia 2000b, Saldiva 1995
	México City	None	1.35%	(0.76% - 1.95%)	**3**	Borja-Aburto 1997, Castillejos 2000
	Santiago	None	0.69%	(0.30% - 1.08%)	**2**	Ostro 1996, Sanhueza 1998
	Sao Paulo	None	0.81%	(0.13% - 1.51%)	**2**	Gouveia 2000b, Saldiva 1995
Infants						
	All Cities	None	2.94%	(1.35% - 4.56%)	**3**	Loomis 1999, Linn 2000, Nishioka 2004
	Sao Paulo	None	2.59%	(0.54% - 4.69%)	**2**	Linn 2000, Nishioka 2004

The results obtained through the meta-analysis are similar to others obtained in others studies. The next figure shows summary estimates from four sources: the PAPA study, a multi-city study of Asian cities [HEI, 2004], the APHEA2 study, that conducted analysis in 29 European cities (Atkinson, Anderson et al. 2001); the NMAPS study that looked at 90 US cities (Samet, Zeger et al. 2000), and finally an independent study by Stieb and colleagues, that looked at the published results of studies conducted in 109 cities worldwide (Stieb, Judek et al. 2002). For the “all ages” case our result is almost the same as the result for the European and for the 109 cities worldwide, although it is more uncertain. For elders, there is only one estimate to compare with, the one by Stieb, which is slightly bigger that ours.

Figure IV-1 Comparison of summary results of the effects of PM_{10} on All Cause



IV.B.2 Mortality Impacts: Cohort Studies

No cohort study of the effects of PM has been conducted in Latin-America, and to our knowledge, only four studies have been conducted worldwide to examine long term mortality, three of them in the USA: the Harvard Six Cities study (Dockery, Pope III et al. 1993) , the California Adventist Study (Abbey, Nishino et al. 1999) , and the so-called American Cancer Society (ACS) Study (Pope III, Thun et al. 1995; Pope III, Burnett et al. 2002; Pope III, Burnett et al. 2004). The only European study (Hoek et al, 2002) associated the risk of premature death to proximity to major roads, so it is not applicable to this analysis.

Of the US studies, the ones by Pope and colleagues had the higher number of subjects considered -- more than a half million people -- followed during a period of 17 years (1982 to 1998). It also has the more sophisticated statistical analysis – including the consideration of both linear and log-linear relative risk models[22] --so we choose to use its estimates. Table IV-5 presents some of the estimates from the cohort studies.

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[22] In a linear model, relative risk of death changes linearly with air pollution concentrations, while in a log-linear model, it changes with the log of the concentrations.

Table IV-5 Risk estimates reported in the studies of the long-term exposure to particulate matter explain entries – central & confidence interval

Cause Location	Age Group	Cohort	C-R Specif.	Exposure metric	% change in deaths for given change in PM2.5 (*)		Source
All Cause mortality							
6 US cities	>24	8,192	Linear	Avg $PM_{2.5}$	**13.2%**	(4.1% - 23.1%)	Dockery, Pope III et al. 1993
151 US cities (ACS cohort)	>30	552,138 adults	Linear	Median $PM_{2.5}$	**5.7%**	(1.5% - 10.0%)	Pope III, Thun et al. 1995
California, USA	>27	6,338 non smoking	Linear	Avg PM_{10}	**0.1%**	(0.1% - 0.1%)	Abbey, Nishino et al. 1999
Cardio-pulmonary mortality							
151 US cities (ACS cohort)	> 30	552,138 adults	Linear	Avg. 79-83 $PM_{2.5}$	**5.9%**	(1.5% - 10.5%)	Pope III, Burnett et al. 2002
				Avg $PM_{2.5}$	**9.3%**	(3.3% - 15.8%)	
			Log-Linear	Avg. 79-83 $PM_{2.5}$	**1.2%**	(0.3% - 2.0%)	Cohen, Anderson et al.
				Avg $PM_{2.5}$	**1.6%**	(0.6% - 2.5%)	
Lung cancer mortality							
151 US cities (ACS cohort)	> 30	552,138 adults	Linear	Avg. 79-83 $PM_{2.5}$	**8.2%**	(1.1% - 15.8%)	Pope III, Burnett et al. 2002
				Avg $PM_{2.5}$	**13.5%**	(4.4% - 23.4%)	
			Log-Linear	Avg. 79-83 $PM_{2.5}$	**1.7%**	(0.3% - 3.1%)	Cohen, Anderson et al. 2004
				Avg $PM_{2.5}$	**2.3%**	(0.9% - 3.8%)	

(*) For linear CR the PM2,5 change considered is 10 ug/m3. For the log-linear CR, the change considered is 10%
For example, if PM2.5 decreases 20%, the % change in lung cancer mortality, based on average PM2.5 (last line), equals -4.6% (2.3 *(-20%/10%))

The use of the US studies in a Latin American context should be undertaken with extreme care. First, the age structure of the population, as well as the underlying causes of death, can be quite different and must be factored into the analysis. For instance, a country with many more young people as a fraction of the total population will not only have a lower baseline death rate but will also appear to be less susceptible to air pollution when looking over the entire population. Looked at another way, a country with few elderly people, say because they die from non-air pollution causes before they become elderly, will appear less susceptible than more elderly. We were not able to directly adjust for this age effect. However, to address the differences in causes of death, we estimated excess deaths from a) all causes, using the results from Pope et al 1995, and b) from cardiopulmonary causes and lung cancer using the results from Pope et al 2002. We added these latter two and compared them to the all cause estimates, choosing the bigger estimate of excess deaths. The second issue is the relationship of PM_{10} to $PM_{2.5}$ in the cities under analysis. We generally do not have $PM_{2.5}$ data for LAC. To apply the linear $PM_{2.5}$ model with PM_{10} concentrations we assumed, in the base case, a ratio of $PM_{2.5}$ to PM_{10} of 0.50. (Bogo, Otero et al. 2003) (Jorquera 2002). This ratio is somewhat lower than the usual one assumed by the USEPA for the USA for example, but the data in LAC shows that the crustal content in PM_{10} may be higher than that in the US. For example, in Santiago, the ratio of monthly data from 1995 to 2001 is 0.47. Had we used the higher ratio, the estimated deaths averted from reducing PM would have been larger, .[23] For the log-linear model using $PM_{2.5}$ data estimates, we assumed that the relative change in $PM_{2.5}$ concentrations is the same as the relative change in PM_{10} concentrations. This might be an underestimation if control measures are aimed at reducing combustion related to PM_{10}. If control measures are aimed at controlling crustal material (resuspended dust from roads, for example), then this assumption is an overestimation, since the relative decrease in $PM_{2.5}$ concentrations will be smaller than the relative decrease for PM_{10}.

The final issue is the difference in PM-10 concentrations between U.S. and Latin American cities. Simply put, air quality in U.S. cities is generally better than in LA cities. The average concentrations in the cities used in the ACS study range from 15 to 25 $\mu g/m^3$ of $PM_{2.5}$, which corresponds to approximately 30 to 50 $\mu g/m^3$ of PM_{10} , using the ratio assumed above. Many of the Latin American cities are in the 60 to 80 ug/m3 range, or even higher.

In extrapolating the US results outside of its original range the shape of the C-R function is critical. While the two functions considered – linear and log-linear – do not differ significantly within the range of the original study, their estimates are quite different when applied to concentrations well outside it, like the ones found in LAC. Since there is evidence that the C-R function is downward sloping, we chose to use the log-linear specification proposed by Cohen et al 2004 for cardio-pulmonary and lung-cancer mortality instead of the linear specification for all cause mortality.[24]

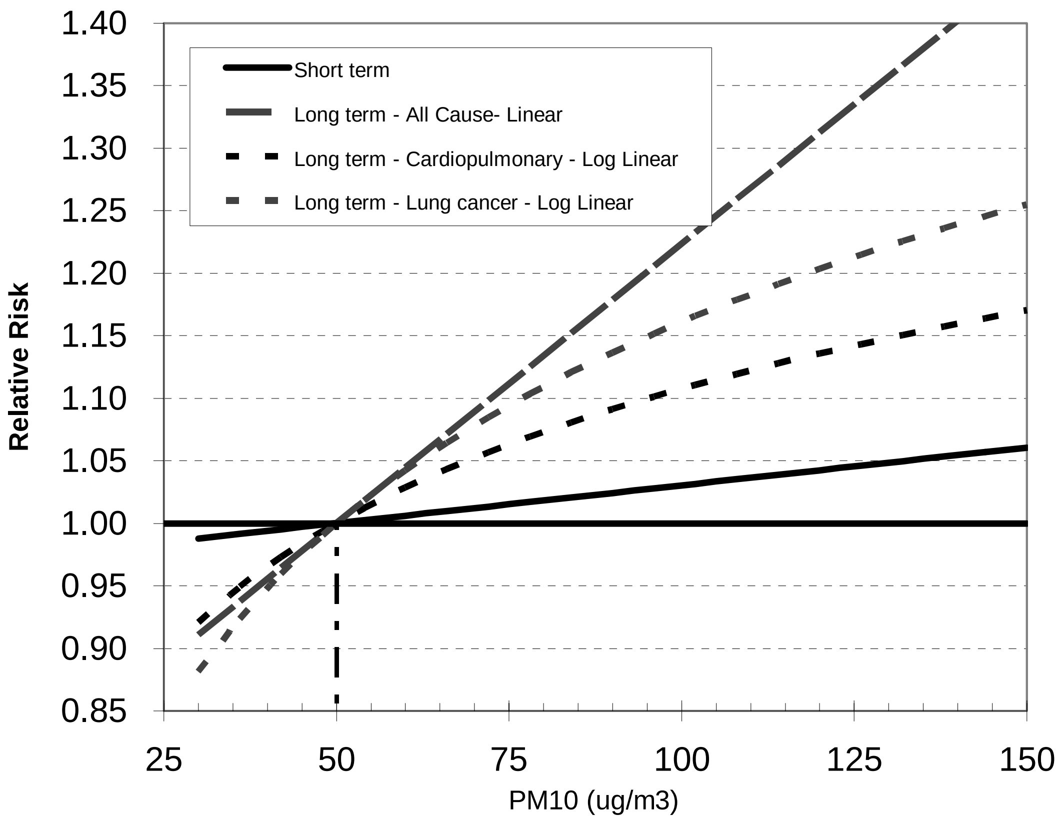
IV.B.3 Summary - Comparison of time-series and cohort coefficients

How do the time-series and cohort coefficients compare? Figure IV-1 shows the concentration response functions for different mortality endpoints, using the case of Buenos Aires for illustration. The curves are anchored at the reference level of 50 $\mu g/m^3$. For example, for Buenos Aires attaining the standard implies a reduction of 60 $\mu g/m^3$ (from 110 $\mu g/m^3$ to 50 $\mu g/m^3$ PM_{10}), or 45%. Mortality risk decreases 3.6% due to the effects of short-tem exposure to air pollution (as taken from time-series studies), while for long-term effects it decreases 27% for

23 There is another, more technical, issue. The Pope et al and Cohen et al estimates are based on three PM metrics: the average of 5 years (1979-83: mean PM2.5 = 21 μg/m3), the average of 1999-2000 (mean PM2.5 = 14) and on the average of both (mean PM2.5 = 17 μg/m3). We used the estimates from the third measure since they include more types of concentration patterns, thereby reducing differences in concentration patterns between LA and the U.S.

the linear model (for all cause mortality) but only 12 and 18% for the log-linear effects on cardiopulmonary and lung cancer deaths respectively.

Figure IV-2 Concentration-response functions for mortality endpoints.



There are several things to note in this figure. First, risks from long-term exposure are much higher than the short-term exposure risks, especially for the linear specifications of the latter[25].This is compatible with the hypothesis that impacts from air pollution are cumulative over time. However, as was mentioned before, the range of concentrations on the original study is approximately 25 to 50 μg/m^3 PM_{10} – it is highly unlikely that the association will be linear outside that range. If it were, in a city like Buenos Aires, about 21% of total deaths would be attributable to air pollution – an implausibly large number. Second, for long-term effects, the log-linear specifications give about the same changes in risk as the linear ones for small reductions in PM10, but for larger changes in PM10, the reductions in risk are much smaller for the log-linear specification.

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[24] This may result in an underestimation of total cases, since there might be other causes of death that may also be associated with air pollution levels.

IV.C Morbidity impacts

IV.C.1 Latin American Studies

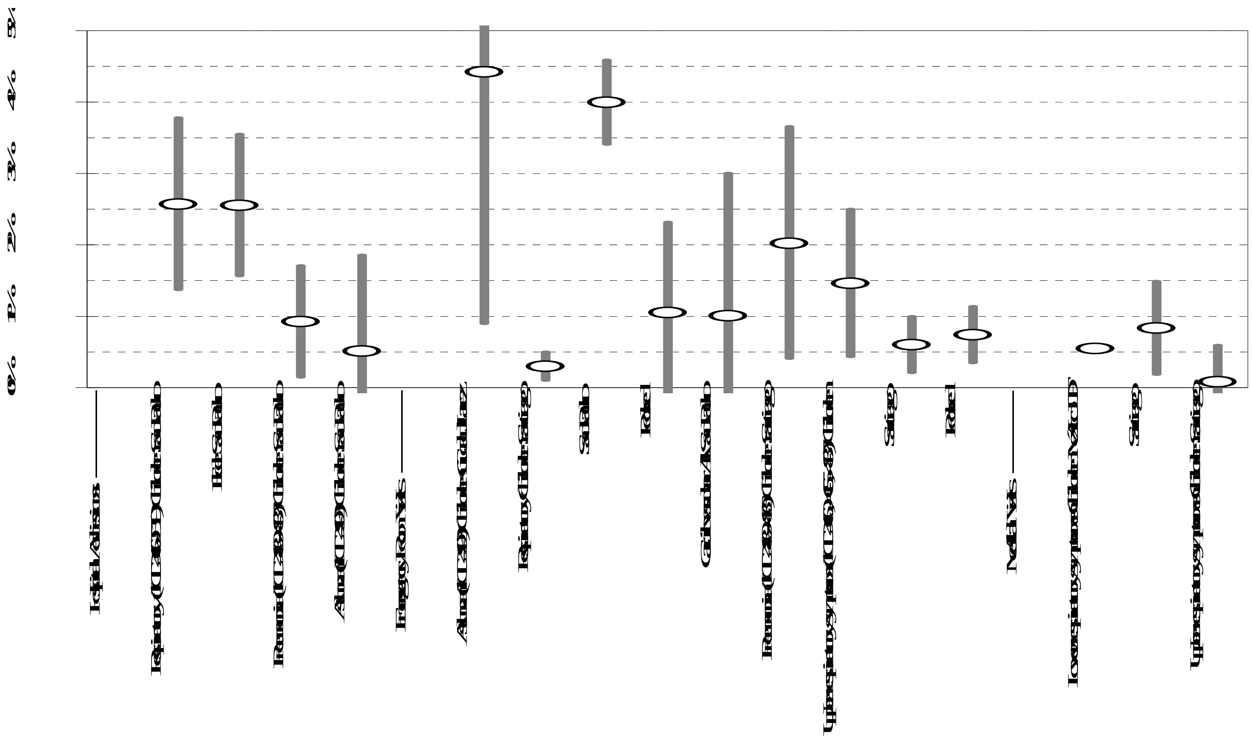
As shown above, fewer studies of morbidity effects have been conducted in Latin America than for mortality effects, and the former have focused only on hospital admissions, emergency room visits, and child medical visits. Most of the studies have been conducted for children, in Sao Paulo, Brazil, as Figure IV-2 shows. All the studies refer to medical actions, from hospital admissions to medical visits, and except for one study (Lin, Amador Pereira et al. 2003) all focus on respiratory related endpoints. The figure shows the estimated percent change in the listed endpoint per 10ug/m3 change in PM10 and also provides uncertainty bounds for these coefficients encompassing the 95% confidence interval (2.5^{th} and 97.5^{th} percentile).

Figure IV-2 shows the mid estimate and the confidence interval for all the endpoints studied. The higher risks correspond to emergency room visits related to general respiratory causes. Next come hospital admissions, also for general respiratory causes. The risk to children and the elderly is almost the same, according to the estimates from three Brazilian studies.[26] Risks for more specific causes are smaller.

[25] It should be noted that the long-term exposure risks are applied to the population older than 30 years. However, most of the deaths in the total population are for people 30 or older, so the estimates are comparable.

[26] Although there are only 3 studies, we have 8 estimates due to two reasons: these studies present results for several sub-age groups within the less than 18 year old bracket, so we lump them together, and one study was performed in Sao Paulo and Rio de Janeiro

Figure IV-2. Percentage increase in baseline effects per 10μg/m³ of PM_{10} for morbidity endpoints in Latin-American studies



Note: bars indicate the 95% confidence interval

IV.C.2 USA Studies

Although the Latin American studies cover several morbidity endpoints, some important ones, especially for WTP, are missing. We complemented the LAC studies with some North-American based studies, used by the US EPA in their Regulatory Impact Analyses (EPA 1997, EPA 1999). The selection from the huge array of studies available aimed to cover some underrepresented endpoints (like all the symptoms and restriction in activity effects) and was conditioned by the availability of incidence rate data.

Table IV-6 Summary of morbidity risk estimates for studies conducted in North American cities

Endpoint	Age group	Co-Pollutant	% Increase per 10 ug/m3 PM10		Reference
Hospital Admissions					
Respiratory Causes (ICD 460-519)	All	none	linear model		Thurston 1994
	Elder	none	**1.7%**	(0.9% - 2.5%)	Pooled
		O3	**2.3%**	-(0.6% - 5.2%)	Schwartz 1995
	All	none	**2.1%**	(0.9% - 3.3%)	Burnett 1997
		O3	**0.3%**	-(1.2% - 1.8%)	Burnett 1997
COPD (ICD 490-496)	Elder	none	**2.6%**	(1.8% - 3.5%)	Pooled
Pneumonia (ICD 480-487)	All	none	**2.7%**	(1.8% - 3.6%)	Burnett 1999
	Elder	none	**1.3%**	(0.8% - 1.9%)	Pooled
Asthma (ICD 493)	Adult	none	**2.6%**	(1.1% - 4.2%)	Sheppard 1999
	Children	none	**2.6%**	(1.1% - 4.2%)	Sheppard 1999
Cardiovascular disease (ICD 390-429)	All	none	**2.3%**	(0.3% - 4.4%)	Burnett 1997
		O3	**1.7%**	-(0.3% - 3.8%)	Burnett 1997
	Elder	none	**1.2%**	(1.0% - 1.4%)	Samet 2000
Dysrhythmia (ICD 427)	All	none	**1.6%**	(0.6% - 2.7%)	Burnett 1999
Emergency Room Visits					
Asthma (ICD 493)	Adult	none	**3.7%**	(1.2% - 6.3%)	Schwartz 1993
	Children	none	**12.0%**	(9.2% - 14.8%)	Norris 1999
Illness & Symptoms					
Acute Bronchitis	Children	none	**16.1%**	-(3.4% - 39.6%)	Dockery et al. 1996
Asthma Attacks	All	O3	**1.5%**	(0.4% - 2.6%)	Whittemore 1980
Shortness of Breath (days)	Children	none	**18.3%**	(2.6% - 36.4%)	Ostro 1995
Restriction in Activity					
Work loss days (WLDs)	Adult	none	**5.2%**	(4.4% - 6.0%)	Ostro 1987
Restricted Activity Days	Adult	none	**2.6%**	(2.3% - 3.0%)	Ostro 1987
Minor Rest. Act. Days	Adult	none	**4.2%**	(3.4% - 5.0%)	Ostro 1989

V. Health Valuation

As noted in Section I, the monetary value of health improvements can be estimated in two broad ways: (i) through measures of monetary outlays and forgone wage compensation – termed the cost-of-illness (COI) approach, and (ii) through measures of what individuals would be willing to give up to obtain health improvements, e.g., willingness to pay (WTP). In this section we present a brief introduction to each method and then discuss the values used in this study.

V.A Values used in the Analysis

For a complete analysis it is necessary to have a value attached to each health effect whose change can be estimated. Ideally, WTP values are the best approximation to the welfare effects deriving from improving air quality. Unfortunately, these values are not generally available so COI estimates are generally used. Another option is transferring values (WTP or COI) from other contexts, as we have done by rescaling USA unit values to apply in a LAC context. In this section we present the values used in this study, which are from both COI and WTP studies.

V.A.1 Available unit values from Latin America and the US

Unit values have been collected from analyses conducted in the US and Europe. But we would prefer to use local values where possible. To that end, we conducted a bibliography search looking for values for health effects in Latin America studies. The main source of data were previous benefit analyses conducted in the region, mainly in Sao Paulo, Mexico City, and Santiago, and also in Buenos Aires, where a study (Conte-Grand 2002) has estimated the co-benefits of GHG mitigation.[27] Table V-1 shows the unit medical costs available for Latin American cities and for the US, while Table V-2 shows the WTP unit values.

The unit medical costs, which one would expect to be more or less in line across countries of a similar level of development, show a wide variation. The values from Holz (Holz 2000) are generally the smaller ones. This might be because those values are derived from epidemiological profiles that are then valued at market prices. Many indirect costs may have not been considered

[27] This study is interesting in the sense that although there are no local epidemiology studies available in Argentina, it develops unit values for some endpoints estimated using transferred value functions.

in that valuation. The most striking dissimilarities come from the two Mexican studies. The McKinley et al study has much bigger values than the Cesar et al. study. McKinley et al considered costs from the health provider (IMSS – Mexican Institute of Social Security) perspective, valuing the highest level of hospitalization for some diseases, which included intensive care unit costs plus attention from staff in the room. In contrast, Cesar et al used the results of a previous study (Hernandez-Avila and al 1995) that was not available for our review. The most striking difference is for chronic bronchitis, where the values differ by a factor of 80 (US$218 vs. $17,750 per case). The Buenos Aires values for medical costs, from Conte Grande 2002, generally fall between these values.

Table V-1 Medical costs for Latin-American cities and the US (US$ per case)

Endpoint	Age Group	Buenos Aires	Mexico City		Santiago	USA
		Conte Grand 2002	*Cesar et al 2000*	*McKinley 2003*	*Holz 2000*	*BenMap*
Hospital Costs						
Chronic Bronchitis	All		218	17,750	2,667	49,651
Hospital Admissions						
Respiratory (ICD 460-519)	All		1,870	2,186	1,455	14,999
	Elder				1,455	17,600
Pneumonia (ICD 480-487)	All	6,293		2,111	1,455	14,693
	Elder				1,455	17,030
COPD (ICD 490-496)	All	6,233		17,750		
Asthma (ICD 493)	Adult				1,455	7,448
	All	4,982		603	1,455	8,098
	Children				1,455	
Cardiovascular disease (ICD 390-429)	All	7,377	5,611	10,890	3,267	20,873
	Elder				3,267	20,607
Congestive Heart Failure (ICD 428)	All			13,300		
	Elder		1,870			
Ischemic Heart Failure (ICD 410-414)	All			8,481		
Dysrhythmias (ICD 427)	All				3,267	14,811
	Elder				3,267	
Emergency Room Visits						
Respiratory (ICD 460-519)	All		91	269	65	261
Pneumonia (ICD 480-486)	All				65	261
	Elder				65	
Upper respiratory symptoms (ICD 460, 465, 487)	All				65	261
	Elder				65	
Asthma (ICD 493)	Adult				65	
	All	154		317	65	322
	Children				65	
Medical Visits						
Lower respiratory symptoms	Children				44	
Upper respiratory symptoms	Children				44	
Illness and Symptoms						
Asthma Attacks	All		337			
Respiratory Symptoms	All		10			

(a) similar to COPD hospitalization

(b) Present value of 10 years of medical costs, 7% discount rate

Table V-2 presents WTP unit values for Mexico City, Santiago, and the US. The Santiago value comes from a CV study developed by one of the authors. The Mexican values are the ones used by McKinley 2003, and come from a WTP study conducted recently in Mexico City (Ibarrarán, Guillomen et al. 2002). That study estimated WTP values for mortality risks, for averting chronic bronchitis, and averting a cold. The values presented in the table are the values from the WTP study.

Table V-2 Unit WTP values for Latin American Cities and for the US studies ($/case)

Endpoint	Age Group	Mexico City		Santiago	USA
		Cesar et al 2000	*McKinley 2003 (*)*	*Cifuentes 2000*	*BenMap*
Reductions in Risk of Death					
Statistical Life	All		506,000	634,000	6,240,000
Chronic Illness					
Chronic Bronchitis	All	118,074	28,000		340,000
Hospital Admissions					
Pneumonia (ICD 480-487)	All	153	330		
COPD (ICD 490-496)	All	153	330		
Asthma (ICD 493)	All	153	330		
CVD (ICD 390-429)	All	153	330		
Congestive Heart Failure (ICD 428)	All	153	330		
chemic Heart Failure (ICD 410-414)	All	153	330		
Emergency Room Visits					
Respiratory (ICD 460-519)	All	79	170		
Asthma (ICD 493)	All	79	170		
Illness					
Asthma Attacks	Adult	15			43.0
Restriction in Activity					
Restricted Activity Days	All				98.0
Minor Restricted Activity Days	Adult	21	20		50.5

(*) The VSL comes from Ibarrarán, Guillomen et al 2002

The Mexican studies have data only for Minor RADs. Since there are US data for both MRADs and RADs, we computed a LA based unit value for RADs based on the Mexican MRAD value multiplied by the ratio of US values for RADs and MRADs (98/50.5)

V.A.2 Transference of WTP Values

As should be apparent from the previous tables, many Latin American cities do not have any locally estimated values, and for many endpoints there are no Latin American values at all. In this case it is possible to "transfer" values from other cities or countries, using the following equation:

$$UV_{\text{Target}} = UV_{Source}\left(\frac{PCI_{\text{Target}}}{PCI_{Source}}\right)^{\eta}$$

where η is the income elasticity of demand for health. The underlying hypothesis in the benefit transfer approach is that valuation differences can be explained primarily by income differences.

An elasticity of 1 would mean that the transferred WTP would be proportional to income differences, while a value of 0 would mean that demand for health is not dependent on income, so the values for the target and source cities should be the same. WTP studies have estimated income elasticities from 0.2 to greater than two (Alberini, Cropper et al. 1997; Bowland and Beghin 2001).

The selection of the way to transfer values (both the metric of income considered and the value of the transfer elasticity) and the source of the original values can produce big differences in the transferred values. For premature mortality, which is the effect whose reduction can produce the biggest benefits, we choose to use the average of the two studies available in LA, adjusting them by per-capita income (PCI) with an elasticity of 1. This elasticity, rather than 0.4, was used because of the similar development patterns of countries in LA compared to that of the U.S.. The Ibarrarán et al 2002 study yields a ratio with respect to the PCI of 64, while the Cifuentes et al 2000 study yields a ratio of 128. For other cities in Latin America, we use the average ratio of VSL to PCI of 96.5 to compute the VSL for all other cities. We also transferred the USA value (US$ 6.24 million per case in 2000 dollars) using the ratio of the purchasing power parity income (PPPI), with a transfer elasticity of 0.4 (Alberini, Cropper et al. 1997; Bowland and Beghin 2001). The transferred values for each city are shown in Table V-3.

The table shows than the values transferred from the USA are much higher than the ones transferred from Mexico and Santiago. This can be explained by three factors: i) The original US value is higher than the Mexico and Santiago values (the ratio with respect to for the US PCI is 178 for the US value, compared to an average of 97 for LAC.), ii) The relative differences in PPPI are lower than the relative differences in PCI – in other words, the income ratio is closer to 1 in the formula above with PPPI., iii) The use of an elasticity of 0.4 instead of 1.0 tends to make the income differences even less significant in transferring the US unit values

Table V-3 Transfer factor and VSL (1000 US$/case) values transferred from two sources: average of LAC and USA

		Source of VSL Value			
		LA		USA	
Country	City	Transfer Factor (PCI city / 1000)	VSL (1000 US$)	Transfer Factor (PPPI city/PPPI USA)	VSL (1000 US$)
Argentina	Buenos Aires	4.9	475	0.65	4,070
	Cordoba	3.8	369	0.59	3,681
	Mendoza	3.2	313	0.55	3,446
Brazil	Campinas	5.1	490	0.67	4,185
	Canoas	9.6	922	0.86	5,389
	Caxias	4.4	423	0.63	3,945
	Cubatao	5.1	490	0.67	4,185
	Curitiba	7.3	705	0.78	4,842
	Itaguai	4.4	423	0.63	3,945
	Porto Alegre	3.3	323	0.57	3,542
	Rio De Janeiro	4.4	423	0.63	3,945
	Sao Joao De Meriti	4.4	423	0.63	3,945
	Sao Jose Do Campos	5.1	490	0.67	4,185
	Sao Paulo	4.4	422	0.63	3,943
	Sorocaba	5.1	490	0.67	4,185
	Vitoria	3.4	323	0.57	3,545
Chile	Calama	3.3	320	0.53	3,305
	Santiago	4.9	475	0.62	3,869
	Temuco	4.8	463	0.61	3,828
Colombia	Bogota	3.4	325	0.62	3,897
	Cali	2.0	189	0.50	3,137
Costa Rica	Heredia	1.6	156	0.39	2,412
	San Jose	2.7	259	0.47	2,954
Ecuador	Guayaquil	2.6	253	0.48	3,007
	Quito	2.5	239	0.47	2,940
El Salvador	San Salvador	2.1	201	0.44	2,762
Honduras	Tegucigalpa	0.4	38	0.25	1,535
	Kingston	2.8	272	0.40	2,497
Mexico	Guadalajara	3.1	295	0.44	2,725
	Juarez	5.9	570	0.57	3,547
	Mexico City	7.9	761	0.64	3,980
	Monterrey	5.9	570	0.57	3,547
	Puebla	5.9	570	0.57	3,547
	Valle De Toluca	3.0	289	0.43	2,704
Nicaragua	Managua	0.4	41	0.17	1,063
Panama	Panama City	1.9	188	0.37	2,285
Perú	Lima	2.2	213	0.47	2,904
Uruguay	Montevideo	4.4	421	0.65	4,062
Venezuela	Caracas	5.4	522	0.52	3,222

Note: Values from the US transfered using PPPI ratios and an elasticity of 0.4. Values from LA transferred using PCI ratios and an elasticity of 1.0.

For the morbidity endpoints we follow the same procedure. Latin American values were transferred using PCI and an elasticity of 1.0, while US values were transferred using PPPI and an elasticity of 0.4. The next table shows the pooled WTP values from all Latin American studies, normalized for an income of $1,000. These values were then transferred to each city based on the PCI.

For the other endpoints there are fewer WTP values.

Table V-4 Pooled unit values from LAC WTP studies (US$ per 1000 $PCI)

Endpoint	Age Group	Latin-American Studies		
		Mid	Number of studies	Range
Reductions in Risk of Death				
Statistical Life	All	96,465	2	64,172 to 128,757
Chronic Illness				
Chronic Bronchitis	All	9,263	2	3,551 to 14,975
Hospital Admissions				
Pneumonia (ICD 480-487)	All	30.6	2	19 to 42
COPD (ICD 490-496)	All	30.6	2	19 to 42
Asthma (ICD 493)	All	30.6	2	19 to 42
CVD (ICD 390-429)	All	30.6	2	19 to 42
Congestive Heart Failure (ICD 428)	All	30.6	2	19 to 42
Ischemic Heart Failure (ICD 410-414)	All	30.6	2	19 to 42
Emergency Room Visits				
Respiratory (ICD 460-519)	All	15.8	2	10 to 22
Asthma (ICD 493)	All	15.8	2	10 to 22
Illness				
Asthma Attacks	Adult	1.9	1	-
Restriction in Activity				
Restricted Activity Days	All	5.0	extrap.	-
Minor Restricted Activity Days	Adult	2.6	2	2.54 to 2.66

Table V-5 shows, as an illustration, the transferred WTP values for two cities,: a high income city (Curitiba, Brazil: PCI=7,309; PPPI=18,595) and a much poorer city (Panama City: PCI= 1,949; PPPI=2,846). The table illustrates the dependence of the transferred WTP values on income, with the Curitiba values being several times the ones for Panama City. It also shows that the relative difference is smaller for the USA transferred values, because of the value of the transfer elasticity.

Table V-5 Transferred WTP unit values to for two cities, Curitiba and Panama City (US$ per case)

	Curitiba, Brazil				Panama City, Panamá			
	LA	USA			LA	USA		
Endpoint	All	All	Children	Adult	All	All	Children	Adult
Chronic Bronchitis	67,703	263,812			18,054	124,521		
Hosp Adm CVD (ICD 390-429)	226.6				60			
Hosp Adm Pneumonia (ICD 480-487)	226.6				60			
Hosp Adm Asthma (ICD 493)	226.6				60			
ERV RSP	116.9				31.18			
ERV Asthma (ICD 493)	116.9				31.18			
Child Medical Visits LRS			25.2				11.9	
Child Medical Visits URS			22.1				10.44	
Acute Bronchitis			276.2				130.38	
Asthma Attacks	14.6	33.4		33.4	3.9	15.75		15.75
Restricted Activity Days (RADs)	36.6				9.75			
Minor Restricted Activity Days (MRADs)	21.9			57.4	5.85			27.1
cute Morbidity any of 19 respiratory symptoms			18.6				8.79	
Shortness of Breath (days)			4.7	4.7			2.2	2.2
Work loss days (WLDs)								

Note: values transferred using a) PCI ratios and a elasticity of 1.0 for LA, and b) PPPI ratios and a elasticity of 0.4 for USA

V.A.3 Transference of Medical Costs

Data for medical costs were available from three cities in LAC, plus the US. To apply them to cities of other countries, we need to adjust them, not by an income indicator as in the WTP case, but by a cost indicator. The best indicator to transfer medical costs would be an indicator based on the unit costs of medical procedures in each country. Unfortunately, to our knowledge, such an indicator is not available. The closest one, the per capita health expenditure statistics [28] from the World Health Organization, reflects total expenditure per person, which is not applicable because of the different health service coverage and age structure of the population, among other factors.

Due to the lack of a better indicator, we choose to use per-capita income. Of course this is an imperfect transfer indicator for this case, since costs of medical procedures are impacted by

[28] See Who National Health Accounts (http://www.who.int/nha/en)

several factors not considered in income. [29] We tried per-capita income and purchasing power parity income, comparing the unit costs for endpoints (i.e. costs normalized per $1000 of income) for those endpoints that had estimates for the three countries plus the US several countries. The comparison shows that costs normalized using the PPPI are more similar across countries than those normalized using PCI[30].is a better indicator. Therefore, we chose to use PPPI as a basis for transferring the medical costs. Table V-6 shows the pooled medical cost estimates from all Latin American studies, normalized for a PPPI of $1,000.

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[29] For example, the cost of imported resources, which may be important in many procedures, is not related to per-capita income.

[30] This comparison implies that we should use a transfer elasticity of 1.0. The number of observations for each endpoint prevent us from testing a different elasticity.

Table V-6 Pooled unit values from LAC medical cost estimates (US$ per case for a PPPI of $1000)

Endpoint	Age Group	Number of estimates	Average
Hospital Costs			
Chronic Bronchitis	All	3	609.4
Hospital Admissions			
Respiratory (ICD 460-519)	All	3	164.4
	Elder	1	137.1
Pneumonia (ICD 480-487)	All	3	281.6
	Elder	1	137.1
COPD (ICD 490-496)	All	2	1,037.6
Asthma (ICD 493)	Adult	1	137.1
	All	3	201.2
	Children	1	137.1
Cardiovascular disease (ICD 390-429)	All	4	592.1
	Elder	1	307.9
Congestive Heart Failure (ICD 428)	All	1	1,167.3
	Elder	1	164.1
Ischemic Heart Failure (ICD 410-414)	All	1	744.3
Dysrhythmias (ICD 427)	All	1	307.9
	Elder	1	307.9
Emergency Room Visits			
Respiratory (ICD 460-519)	All	3	12.6
Pneumonia (ICD 480-486)	All	1	6.1
	Elder	1	6.1
Upper respiratory symptoms (ICD 460, 465, 487)	All	1	6.1
	Elder	1	6.1
Asthma (ICD 493)	Adult	1	6.1
	All	3	15.6
	Children	1	6.1
Medical Visits			
Lower respiratory symptoms	Children	1	4.1
Upper respiratory symptoms	Children	1	4.1
Illness and Symptoms			
Asthma Attacks	All	1	29.6
Respiratory Symptoms	All	1	0.9

V.A.4 Lost Productivity values

Lost productivity values are computed from the average days lost due to occurrence of a case times the average daily wage for the city. Income figures are readily available. For the duration of the effects, we relied on data from Mexico City and from Santiago, as shown in Table V-7.

It should be noted that these are only days spent in the hospital (except for chronic bronchitis, for which a duration of 10 years is assumed). Probably individuals who spent time at the hospital will require a period of convalescence, increasing their productivity loss. These data are not available from hospital admission records. For the calculations we estimated that the individual requires a convalescence period of half the time spent in the hospital.

Table V-7 Average Length of stay for hospital admissions (days per case)

	Santiago				México City	
Endpoint	**All**	**Children**	**Adult**	**Elder**	**Intensive Care Unit**	**Hospital days**
Chronic Bronchitis			10yr	10yr		
Hospital Admissions						
CVD (ICD 390-429)	8.4	8.1	8.2	9.3		
Congestive Heart Failure					5	7
AMI					7	15
Dysrhythmias (ICD 427)	6.8		6.8	9.3		
RSP (ICD 460-519)	8.8	8.2	8.9	9.0		
Pneumonia (ICD 480-487)	6.9		6.9	11.6		7
Asthma (ICD 493)	6.8	5.3	7.3	6.7		2
COPD					10	15

(*) Corresponds to total disability period, not only hospital stay
Sources:
Santiago: averages from the whole country, from the 1996 Hospital Discharges database from the Ministry of Health computed in Cifuentes, 2001.

México City: values from the IMSS reported in McKinley 2003

We assumed that in the case of children and the elderly, an adult will take care of them for some fraction of the time. For children, we assumed 50% of the time spent by an adult. For the elderly, we assumed 25%.

We value these effects at an average daily wage, computed as the annual per-capita income divided by 365 days, since the illness can affect both workdays and holidays, and both employed and unemployed people[31].

To value the days of lost work estimated directly from the corresponding CR function we used the average daily wage of the employed population. The average daily wage was computed as the annual per-capita income divided by 260 workdays per year (assuming holidays are valued at the same rate) and by the fraction of the employed population. Unemployment rates for urban areas were obtained from the Statistical Yearbook of ECLAC (ECLAC 2002)

VI. Scenario Definition and Analysis Strategy

Scenarios were developed for the magnitude of the ambient concentrations reduction (Pollution Reduction scenarios), for the quantification of the health effects given a change in concentrations (Health scenarios), and for the unit values used to monetize these effects (Valuation scenarios). To address the uncertainties present at many points in the analysis, we analyzed alternative scenarios where the uncertainties couldn't be characterized by statistical uncertainty but reflected discrete options for modeling.

VI.A Pollution reduction scenarios

Since we did not analyze a specific set of pollution reduction measures, we choose to analyze two scenarios that represent what we called 'canonical' cases of pollution reductions.

Because all the recent scientific evidence shows that there is no threshold for the effects of PM_{10}, our first scenario (C1) considers a uniform reduction of 10% in the annual ambient concentration of PM_{10} in each city. We choose to specify a percentage reduction instead of an absolute reduction in concentrations, because it is expected that more polluted cities will try to make bigger reductions than less polluted ones.

We know that in general, developing countries are more polluted that the developed ones, and that they frequently do not comply with the "internationally accepted" ambient air pollution standards (or with their own standards, when they have them). So, our second scenario (C2) is

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[31] This is an overestimation though, because if there is somebody unemployed in a household, that person would take care of the sick person before any employed person. However, this is not likely to be important.

simply a scenario in which each city complies with a reference concentration of 50 μg/m^3 PM_{10}. We choose this value because it is the current US annual standard for PM_{10}, and coincides with the standard adopted in many LAC countries.

In terms of these scenarios, under scenario (C1) the cities with the highest baseline make the largest pollution reduction, with every city making some reduction. Under scenario (C2), the cities with concentrations already below the standard do nothing, while concentrations in the other 26 generally are far larger than in Scenario C1.

VI.B Quantification of health impacts reduction

In calculating health status changes, we considered two alternative scenarios that use different transfers of health coefficients:(E1) Latin American studies applied to all the cities of the country of origin of the study; plus pooled Latin American estimates to fill in missing gaps in C-R functions; and (E2) transfer of log-linear U.S. C-R functions directly to Latin American cities.

VI.C Valuation Scenarios

Similarly, we considered two possible valuation scenarios: (V1), which values effects in cities with local country valuation functions plus adjusted values from Latin-American studies to countries with no data; and (V2) which transfers unit values from the U.S. to all cities. For V1, the mean values from Latin American studies were transferred using PCI ratios and a transfer elasticity of 1.0. For V2 the WTP estimates from the US were transferred using PPPI ratios with a transfer elasticity of 0.4. For both scenarios medical costs were transferred using PPPI ratios with a transfer elasticity of 1.

VI.D Scenarios Summary

Multiplying the 2 health scenarios by the 2 valuation scenarios yields 4 scenario combinations for each of the two pollution reduction scenarios (C1 and C2), for a total of 8 scenarios. It is important to notice that although numerically all these scenarios are treated in the same way, they represent different entities. The pollution reduction scenarios (C1 and C2) represent two very different reduction cases (analyses cases) while the health and valuation scenarios are necessary because of the current lack of information for each city. In this sense, the E and V scenarios represent model uncertainty, while the C scenarios represent two different types of pollution reduction cases.

VI.E Aggregation of effects and benefits

Both effects and benefits are computed for each endpoint and for each age group, for which there are available data. To compute the total change in effects and the total benefits, they need to be aggregated over age groups and over endpoints. However, care must be taken when performing this aggregation to avoid double-counting.

VI.E.1. *Aggregation by Age Groups.*

Effects and benefits are computed for each of the three age groups we have defined (children, adults, elderly) [32] or for the whole population with no distinction by age. In some cases there are C-R and value functions for some of these groups (for example, for adults and elderly and for the whole population). Of course, specific age group estimates cannot be added to the All ages estimates, but they can be added together and then compared to the All ages estimate. We did this comparison for all effects and benefits, and in each case choose the aggregate estimate that produced the highest value for each of them. It is important to note that since unit values are not the same for different age groups, the aggregation method that gave the highest estimate of effects was not necessarily the same as for the benefits.

VI.E.2. *Aggregation by Endpoints*

Since some endpoints are included within others – for example, hospital admissions for asthma are included into respiratory hospital admissions -- it is necessary to compute the net effects for each endpoint to avoid double counting.

For Hospital Admissions, Dysrhytmias (ICD9 427) were subtracted from Cardiovascular disease (ICD9 390-429), while Pneumonia (ICD9 480-487) and Asthma (ICD9 493) were subtracted from All Respiratory Causes (ICD9 460-519). For Emergency Room Visits, Upper respiratory symptoms (ICD9 460, 465, 487), Pneumonia (ICD9 480-486) and Asthma (ICD9 493) were subtracted from Respiratory Causes.

For days with restriction in activity, Work Loss Days (WLDs) were subtracted out of Restricted Activity Days (RADs), while these were in turn subtracted from Minor Restricted Activity Days

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[32] These are the generally defined age groups. For some endpoints, specific age groups are defined (for example, acute bronchitis impacts are estimated for children aged 8 to 12)

(MRADs), to avoid double counting. Due to the differences in studies and in the quality of the health information, it might happen that a specific endpoint yields a bigger estimate than a more general one that includes it. In that case, the more general endpoint estimate was set to zero, not to a negative number.

VI.E.1.1 Mortality impacts aggregation:

Mortality is one of the main sources of benefits. We could estimate both the time-series (short-term) exposure effects (based on local Latin-American studies), and the cohort-based (long-term) exposure effects (based on US studies). The E1 scenario includes only short-term exposure mortality because only that type of study is available in LA. The E2 scenario includes long-term exposure mortality, as in most studies of this type assume that long-term mortality models already capture the short-term effects (and indeed, the mortality coefficient for the long-term effects is three times that for the short-term effects). This difference is likely to be the single most important difference in our scenarios.

For the E1 scenario, we compared the estimates from the All age group with the sum of the Children and Elder estimates, using the higher estimate in each city. For the E2 scenario all the premature deaths were computed for the population older than 30 years (following the population canvassed in the Pope et al study), but we used the higher death estimate comparing the All Causes estimates with the sum of the Cardio-pulmonary and Lung Cancer estimates. Additionally, we also consider a linear and log –linear specification for the long-term mortality function (under E2) .

Values for foregone output (lost productivity) and medical treatment costs are summed, and labeled Cost of Illness (COI) values. The willingness to pay estimates for each Latin American city are presented separately.

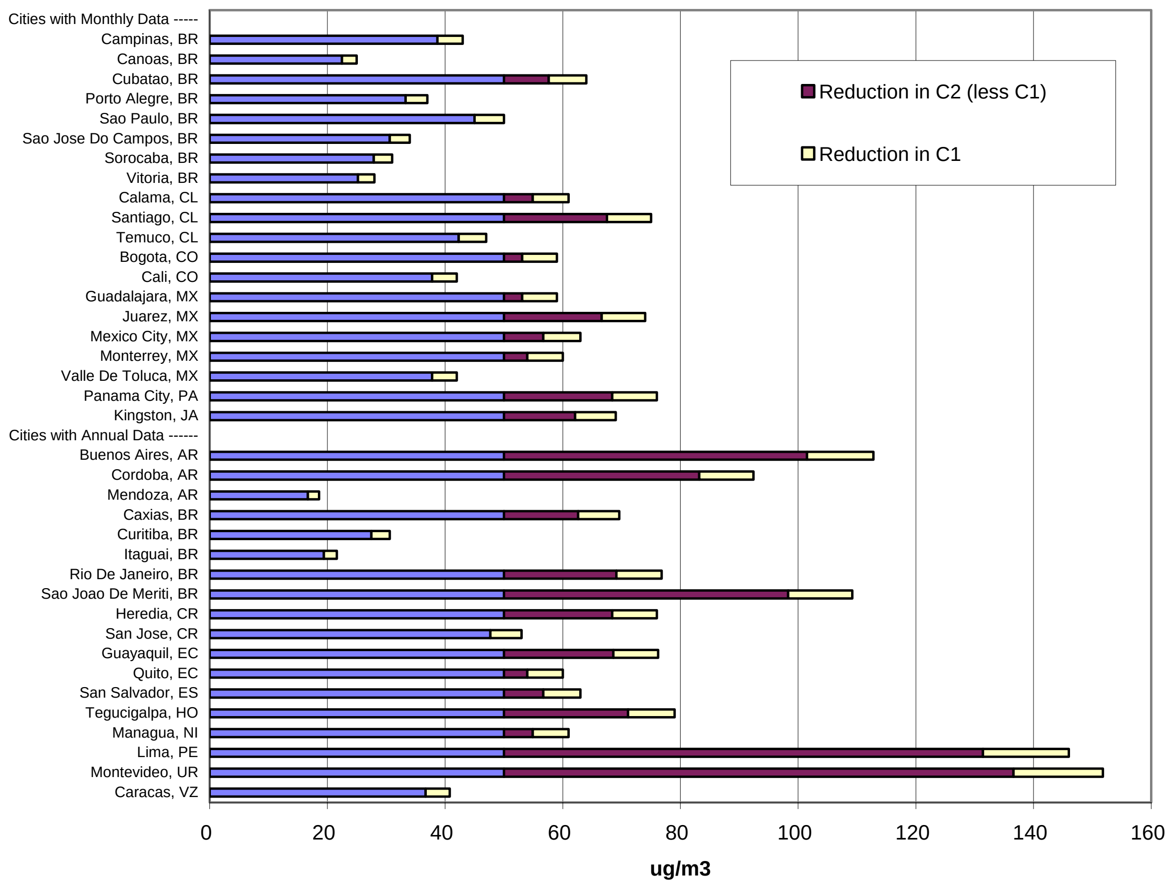
VII. Results

Below, we present results for each stage of our damage function analysis and for the various scenarios. First, we present the air quality improvements associated with our scenarios. Then, we present the reduction in the number of cases for each of the endpoints analyzed. Later, we present the monetized benefits associated with the reduction in cases. Then, we present an analysis that decomposes the results to explain the causes of differences in benefits across cities. Finally, we compare our results to some published analyses of the benefits of air pollution reductions.

VII.A Air Quality Improvements

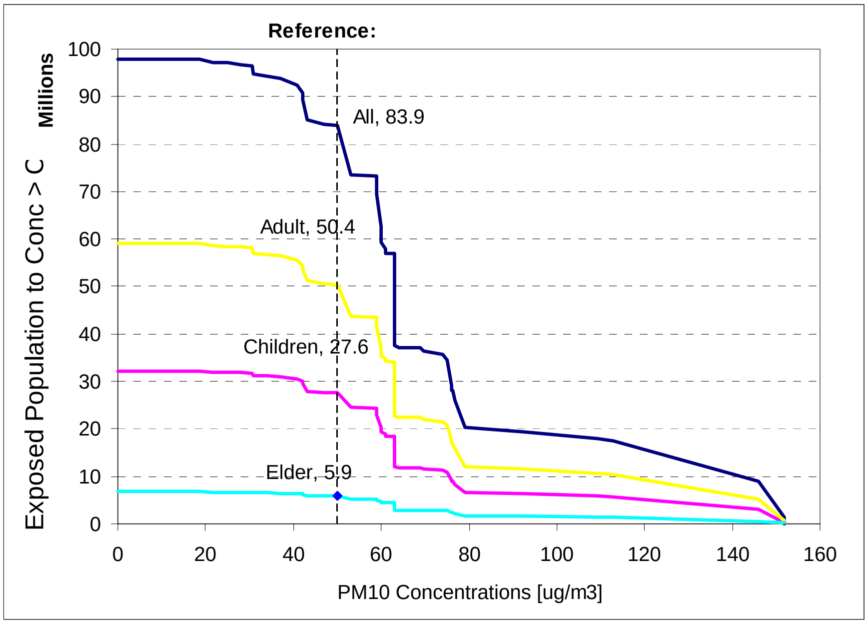
Figure VII-1 provides baseline concentrations and post-control scenario concentrations for each city by scenario. The full length of the bar is the baseline, the reduction in concentrations in C1 is registered by the first area to the left of the furthest extent of the bar and the further reduction in concentrations (if any) from the C2 scenario is registered by the next area of the bar. The remaining area of the bar is the concentrations left after application of the C2 scenario (or C1 scenario where there is no change for C2). A significant fraction of the 41 cities exceed the annual standard (50 ug/m3), with the highest concentrations registered in Tegucigalpa, Honduras, exceeding the standard by over 4 times. Of this group, thirteen cities have PM10 concentrations below the standard, so the reduction required in C2 is null.

Figure VII-1 Baseline and two control scenarios for PM_{10} concentrations reductions, by city (μg/m^3 annual average).



However important the concentrations are, the most important metric is the population exposure, i.e. the number of people exposed to a certain concentration. We have computed the total exposure for all cities, by age group, as shown in Figure VII-2. This figure shows that, of the almost 100 million people of the cities considered, a stunning 84 million are exposed to concentrations at or above the reference value of 50 μg/m^3 , of which almost 28 million are children. Even when only A cities are considered, for which data quality is less of a concern, the figure is still high, up to 44 million.

Figure VII-2 Population exposure by age group and PM concentration



VII.B Health effects reductions

VII.B.1 Mortality effects

Premature mortality cases were computed applying the corresponding C-R functions and PM_{10} concentrations to the baseline cases. Table VII-1 provides estimated mortality effects for the year 2000 for control scenarios C1 and C2, for the two health scenarios E1 and E2 (recall the E1 scenario is based on a linear C-R function, while the E2 uses a log-linear specification.) .

The difference in magnitude between the E1 and E2 scenarios stems from two facts: the different specification of the concentration-response functions, and the different causes of death considered in each scenario. For E2 the relative size of the death reductions is more important than its magnitude. On average E2 deaths reduced are 23% higher than for E1, but for the A cities, which have lower baseline concentrations, E2 death are reduced 39% more than E1 deaths, while for the B cities, which have higher baseline concentrations, E2 deaths are reduced only 7% more.[33]

The differences between estimates of deaths averted across the two control scenarios ranges from about 50% (270 vs. 130 for Lima) to 600% (9 vs. 52 for Mendoza) for the C1 case, and from 80% (1700 vs. 1300, again for Lima) to 260% for the C2 scenario (62 vs. 160 for Panama City). These differences are due to what may be termed model uncertainty, i.e. the model chosen to represent the impacts of air pollution. There also is statistical uncertainty, which arises from the fact that the coefficients on the C-R functions are estimated. Both statistical and model uncertainty are discussed later.

Of all the cities, Buenos Aires and Mexico City, by virtue of their large population, bad air pollution and high mortality coefficients, are far and away the greatest beneficiary of a policy to reduce PM_{10} , whether by 10% or to the annual standard. For Buenos Aires, the premature death

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[33] Note the different causes of death considered in the E1 and E2 scenarios. For the E1 case, we use all cause mortality, while for the E2 case, we estimate the deaths reduced as cardiopulmonary plus lung cancer deaths. As we said before, there might be other causes of death that are affected by air pollution that are not considered within these two groups. Also, the incidence rate data for these causes is more prone to error than the total mortality data, and it might be underestimated. The protocol to assign causes of death may differ from country to country, and with respect to the protocol used in the USA, where the original study was conducted. Lung cancer deaths are more difficult to misclassify than cardiopulmonary deaths, but the bulk of the effects are for the latter causes.

reductions are over five times with a C2 policy versus a C1 policy, while for Mexico they are almost double. In all cases, these death reductions represent a large fraction (from 20 to 30% for Buenos Aires and 10 to 25% for Mexico City) of the total deaths avoided.

Type A cities amount to about half of the cases for scenario C1, but only for 22-26% for the C2 scenario, where type B cities, due to their higher concentrations, have the biggest share of cases. In that scenario, four cities not associated with high pollution problems, like Buenos Aires, Rio de Janeiro, Lima and Montevideo, each amount to more than 10% of the premature deaths reductions.

Table VII-1 Baseline cases and reduction in mortality cases for control scenarios in the year 2000 (cases per year)

Country	City	Baseline Effects	C1 - 10% reduction E1	C1 - 10% reduction E2	C2 - Annual Standard E1	C2 - Annual Standard E2
Cities with Monthly Data						
Brazil	Campinas	5,640	16	42		
	Canoas	1,640	3	12		
	Cubatao	470	2	3	4	8
	Porto Alegre	9,130	23	69		
	Sao Jose Do Campos	2,260	5	16		
	Sao Paulo	58,300	180	450		
	Sorocaba	2,710	6	20		
	Vitoria	1,650	3	12		
Chile	Calama	644	2	5	4	10
	Santiago	30,700	140	240	460	940
	Temuco	1,400	4	11		
Colombia	Bogota	26,000	120	210	190	330
	Cali	16,300	55	130		
Jamaica	Kingston	3,550	21	37	56	110
Mexico	Guadalajara	18,600	120	120	190	190
	Juarez	4,290	32	25	100	91
	Mexico City	107,000	760	690	1,600	1,500
	Monterrey	13,000	79	79	130	140
	Puebla	5,970	35	38	26	28
	Valle De Toluca	4,520	20	26		
Panama	Panama City	3,930	18	41	62	160
Cities with Annual Data						
Argentina	Buenos Aires	67,100	560	560	3,100	4,600
	Cordoba	11,100	77	93	360	580
	Mendoza	6,310	9	52		
Brazil	Caxias	3,940	19	28	59	100
	Curitiba	8,570	18	63		
	Itaguai	407	1	3		
	Rio De Janeiro	41,500	220	320	830	1,400
	Sao Joao De Meriti	2,420	18	18	98	140
Costa Rica	Heredia	425	3	3	8	13
	San Jose	1,590	6	13	4	7
Ecuador	Guayaquil	9,980	64	59	230	260
	Quito	6,690	33	39	54	67
El Salvador	San Salvador	1,970	9	10	19	22
Honduras	Tegucigalpa	3,020	15	32	53	140
Nicaragua	Managua	3,420	20	19	36	36
Peru	Lima	24,700	270	130	1,700	1,300
Uruguay	Montevideo	14,500	160	120	1,100	1,400
Venezuela	Caracas	8,640	28	69		
	A Cities	*301,000*	*1,640*	*2,280*	*2,820*	*3,510*
	B Cities	*220,000*	*1,530*	*1,630*	*7,650*	*10,100*
	All Cities	***521,000***	***3,170***	***3,910***	***10,470***	***13,610***
	% of baseline		**0.6%**	**0.8%**	**2.0%**	**2.6%**

Notes: Figures rounded to 2 significant digits. Totals may no add up exactly
For E1 the estimates correspond to short-term, all cause mortality
For E2 they correspond to long-term, cardiopulmonary plus lung cancer mortality

So far the discussion has been comparative. How large in an absolute sense are the health improvements? For Mexico City, a 10% reduction in annual PM_{10} levels results in somewhere between 690 and 760 premature deaths avoided. These estimates may be compared to the Mexico City population of 8 million, and with an estimated number of deaths each year of 107,000, 61,000 of which are elderly. At the other end of the impact range, avoided premature deaths for Calama, Chile, are between 2 and 5.

VII.B.2 Morbidity Impacts

Because there are so many different types of morbidity endpoints and in terms of total benefits they don't amount to a large share of the total, we present these morbidity results in less detail that the mortality results. Table VII-2 presents a summary of health effects aggregated by endpoint group, for the E1 (LAC) and E2 (USA) scenarios and for both control scenarios, added over all cities, but distinguishing cities with reliable air quality data (type A) from cities with less reliable data (type B). The difference between the E1 and E2 scenarios arises basically from the difference between the C-R coefficients for the Latin-American and US studies. It also reflects the greater coverage of endpoints by the US based studies.

Table VII-2 Reduction in morbidity cases per year by major endpoint group for type A and type B cities.

(a) C1 scenario: 10% reduction

Scenario	Endpoint Group	Cities A	Cities B	Total
LAC	Hospital Admissions	4,600	5,100	9,800
	Emergency Room Visits	15,000	14,000	29,000
	Medical Visits	31,000	41,000	71,000
USA	Chronic Bronchitis	8,800	12,000	21,000
	Hospital Admissions	15,000	16,000	31,000
	Emergency Room Visits	2,500	2,400	4,900
	Work Loss Days	2,000,000	1,800,000	3,800,000
	Restricted Activity Days	11,000,000	10,000,000	21,000,000
	Symptoms	20,000,000	19,000,000	39,000,000

(b) C2 scenario: Annual Standard

Scenario	Endpoint Group	Cities A	Cities B	Total
LAC	Hospital Admissions	7,400	25,000	32,000
	Emergency Room Visits	16,000	66,000	83,000
	Medical Visits	40,000	200,000	240,000
USA	Chronic Bronchitis	13,000	48,000	61,000
	Hospital Admissions	22,000	79,000	100,000
	Emergency Room Visits	3,900	11,000	15,000
	Work Loss Days	3,200,000	8,600,000	12,000,000
	Restricted Activity Days	17,000,000	48,000,000	64,000,000
	Symptoms	31,000,000	78,000,000	110,000,000

There are several results to observe about this table. First, since most of the cities have concentrations that are higher than the annual standard (on average more than 10% higher), the benefits from the C2 scenario are greater than in the C1 scenario. Second, reductions in hospital admissions are about three times larger for the US scenario (E2), mainly because of the greater coverage of different hospitalization endpoints. Also, the USA scenario includes endpoints that are not considered at all in the LA scenario.

VII.C Benefits

In this section the monetary benefits of improving air quality in Latin American cities are presented, first by endpoint group, then by city. Then we present the decomposition analysis by computing benefits in dollars/person and dollars per person/ug/m3 change in PM_{10} .

VII.C.1 Benefits by Endpoint Group

Table VII-3 presents the aggregated benefits for all Latin American cities (distinguishing type A and type B cities) for a 10% reduction in concentrations (Scenario C1) and reaching the 50 ug/m3 target (C2 Scenario). Benefits based on WTP and COI values are distinguished. Within each of these value estimates Latin American C-R functions and values are used (LAC scenario) and USA C-R functions and values are uses (USA Scenario). Figures are rounded to two significant digits, so the totals may not match.

Table VII-3 Benefits By Endpoint Group (Million of US$ per year)

Benefits	Scenario	Endpoint Group	C1 - 10% reduction			C2 - Annual Standard		
			Cities A	**Cities B**	**Total**	**Cities A**	**Cities B**	**Total**
WTP								
	LA	Mortality	1,100	670	1,700	1,900	3,300	5,200
		Hospital Admissions	0.10	0.06	0.16	0.17	0.31	0.49
		Emergency Room Visits	0.09	0.06	0.15	0.16	0.28	0.44
		Total	**1,100**	**670**	**1,700**	**1,900**	**3,300**	**5,200**
	USA	Mortality	21,000	24,000	45,000	33,000	110,000	150,000
		Chronic Bronchitis	1,700	2,300	4,000	2,600	9,100	12,000
		Restricted Activity Days	430	390	820	680	1,800	2,500
		Symptoms	81	77	160	120	300	430
		Total	**23,000**	**27,000**	**50,000**	**37,000**	**120,000**	**160,000**
Medical Costs								
	LA	Hospital Admissions	8.90	8.60	17.00	14.00	42.00	56.00
		Emergency Room Visits	0.06	0.05	0.12	0.10	0.25	0.35
		Medical Visits	1.20	1.40	2.50	1.50	6.80	8.30
		Total	**10**	**10**	**20**	**16**	**49**	**65**
	USA	Chronic Bronchitis	170	220	400	260	880	1,100
		Hospital Admissions	74	74	150	110	360	470
		Total	**250**	**300**	**540**	**370**	**1,200**	**1,600**
Lost Productivity								
	LA	Mortality	63	42	100	110	210	320
		Hospital Admissions	0.15	0.14	0.30	0.27	0.70	0.97
		Emergency Room Visits	0.02	0.01	0.03	0.02	0.06	0.08
		Medical Visits	0.03	0.03	0.07	0.05	0.17	0.21
		Total	**63**	**42**	**110**	**110**	**210**	**320**
	USA	Mortality	180	150	320	300	670	970
		Chronic Bronchitis	660	660	1,300	1,100	2,600	3,600
		Hospital Admissions	2	2	4	4	9	12
		Emergency Room Visits	0	0	0	0	0	0
		Work Loss Days	68	43	110	120	200	320
		Restricted Activity Days	64	44	110	110	200	310
		Total	**970**	**890**	**1,900**	**1,600**	**3,600**	**5,200**

Note: COI estimates for mortality are based on Human Capital.

As expected, total benefits based on WTP are far larger than those based on COI. In fact, the former are about 13-20 times larger for the C1 scenario and 14-24 for the C2 scenario. The main component of WTP values is mortality reductions; all other endpoints contribute much less to the benefits.

Using Latin American values rather than transferred USA values also makes a big difference -- transferred USA benefits are about 30 times greater than LAC benefits. This difference stems from both the different number of cases considered and the unit values. The main difference comes from the unit value, though: the difference in excess death reductions for example is only about 30%, while the difference in the VSL can be as large as 20 times.

VII.C.2 Benefits by City

Table VII-4 shows benefits by city, for the two control scenarios considering the WTP values for Latin America (LA scenario) and the U.S. (USA scenario), using the corresponding C-R functions from each scenario. The table shows a large variation in benefits among cities. Part of the variation of scenario C1 stems from the different levels of baseline pollution Scenario C2 leads to greater variation, since some cities already comply with the PM10 standard.

Consider Mexico City. This city can benefit greatly from improving air quality. Reaching the 50 ug/m3 standard is estimated to result in yearly benefits ranging from $1.3 billion to $17 billion (calculated from WTP values). Santiago would also benefit significantly. Many type B cities, such as Buenos Aires, also seem to have very significant potential benefits.

It is also interesting to note that such a relatively small (10%) reduction in pollution can lead to significant benefits in many of the cities, even with the log-linear transferred C-R function. In fact, 17 cities obtain benefits greater than $10 million per year for the LA scenario, while all of them do for the USA scenario. As a 10% improvement should not be very expensive because of the low quality fuels, poor maintenance practices and generally inefficient production and abatement operations of industry, these benefits may well be higher than the required abatement costs.

Table VII-4 Total benefits by City (WTP values)

		C1 - 10% reduction				C2 - Annual Standard			
		M US$		As % of income		M US$		As % of income	
		LAC	USA	LAC	USA	LAC	USA	LAC	USA
Type A Cities									
Brazil	Campinas	9	220	0.2%	4.4%				
	Canoas	3	74	0.1%	2.5%				
	Cubatao	1	20	0.2%	3.7%	2	46	0.4%	8.4%
	Porto Alegre	8	290	0.2%	6.3%				
	Sao Jose Do Campos	3	83	0.1%	3.5%				
	Sao Paulo	85	2,000	0.2%	4.4%				
	Sorocaba	3	98	0.1%	3.9%				
	Vitoria	1	50	0.1%	5.1%				
Chile	Calama	1	23	0.2%	5.0%	2	42	0.3%	9.2%
	Santiago	74	1,100	0.3%	4.3%	240	4,200	0.9%	15.9%
	Temuco	2	53	0.2%	4.5%				
Colombia	Bogota	45	1,200	0.2%	5.1%	68	1,800	0.3%	7.9%
	Cali	12	550	0.1%	6.5%				
Jamaica	Kingston	6	110	0.3%	5.9%	17	320	0.9%	17.4%
Mexico	Guadalajara	41	460	0.4%	4.0%	62	720	0.5%	6.2%
	Juarez	21	160	0.3%	2.2%	66	540	0.9%	7.5%
	Mexico City	650	3,400	0.4%	2.3%	1,300	7,400	0.9%	4.9%
	Monterrey	51	440	0.3%	2.3%	85	740	0.4%	3.8%
	Puebla	22	190	0.3%	2.5%	16	140	0.2%	1.9%
	Valle De Toluca	6	100	0.2%	2.7%				
Panama	Panama City	4	130	0.2%	7.9%	13	480	0.8%	29.8%
	Total A cities	**1,100**	**11,000**	**0.3%**	**3.3%**	**1,900**	**16,000**	**0.8%**	**6.4%**
Type B Cities									
Argentina	Buenos Aires	300	3,200	0.7%	7.5%	1,700	23,000	3.9%	53.1%
	Cordoba	32	450	0.6%	8.6%	150	2,600	2.9%	49.2%
	Mendoza	3	190	0.1%	7.0%				
Brazil	Caxias	9	160	0.3%	4.8%	28	540	0.8%	15.9%
	Curitiba	14	360	0.1%	3.1%				
	Itaguai	0	13	0.1%	3.7%				
	Rio De Janeiro	110	1,700	0.4%	6.5%	400	7,000	1.5%	27.3%
	Sao Joao De Meriti	9	110	0.4%	5.8%	47	750	2.4%	38.0%
Costa Rica	Heredia	0	12	0.3%	7.6%	2	45	0.9%	28.0%
	San Jose	2	49	0.2%	5.9%	1	27	0.1%	3.3%
Ecuador	Guayaquil	18	280	0.4%	5.4%	67	1,100	1.3%	21.7%
	Quito	9	170	0.3%	4.9%	15	290	0.4%	8.3%
El Salvador	San Salvador	2	47	0.2%	4.7%	4	99	0.4%	9.9%
Honduras	Tegucigalpa	1	72	0.2%	21.4%	2	290	0.7%	86.4%
Nicaragua	Managua	1	33	0.3%	9.1%	2	61	0.5%	16.7%
Peru	Lima	66	1,100	0.4%	6.4%	410	7,200	2.5%	43.3%
Uruguay	Montevideo	78	700	1.3%	11.6%	510	6,400	8.5%	107.0%
Venezuela	Caracas	16	280	0.2%	2.8%				
	Total B cities	**670**	**8,900**	**0.5%**	**6.5%**	**3,300**	**49,000**	**2.9%**	**43.4%**
	All Cities	**1,700**	**20,000**	**0.4%**	**4.3%**	**5,200**	**66,000**	**1.4%**	**18.1%**

Note:. Figures for cities rounded to two significant digits. Totals and percentages computed from non-rounded values

VII.C.3 Decomposition Analysis

Variation in total benefits across cities can be caused by a host of factors, such as differences in population, differences in the age distribution, the degree of ambient improvement, baseline health risks, and other factors. To begin to disentangle these influences, we present benefits in per capita terms (US$/person/year) to remove the effect of different populations, and also by unit concentrations (US$/person/year/(μg/m^3) to also remove the effect of differing magnitudes of concentration magnitudes.

As shown in tables VII-5 and VII-6, per capita benefits for the C1 scenario have a huge range -- from as little as $0.20 to $65 per person per year for COI values. But the levels of these COI benefits are dwarfed by those using WTP measures -- from $0.70 to $2200 per person. For the C2 scenario the per capita benefits are even greater because the concentration reductions are considerably larger. The differences for the LA scenario reflect differences in city characteristics, such as concentration levels, baseline mortality, per capita income and C-R functions[34].

The highest benefits per capita are for Montevideo and Buenos Aires (500 and 370 US$/person/year for the C1 scenario and 4,700 and 2,600 for the C2 scenario, respectively. These values result from a combination of relatively wealthy (PPP=$11985 and $12081) but very polluted (Avg PM_{10}=158 and 117μg/m^3 respectively) cities.

The average per capita benefits for all cities analyzed, for a 10% reduction in air pollution are $17/person for the LA scenario and $500/person for the USA scenario, for WTP values. For COI values, the average benefits are $1.30 for the LA scenario and $24 for the USA scenario. This shows that a modest 10% reduction in particulate air pollution levels can have significant benefits for each person of the cities analyzed.

Per capita benefits corrected for differences in changes in concentrations are shown in the last column of tables VII-5 and VII-6). For the whole region, the population weighed average baseline concentration is 74.7, so the 10% reduction for scenario C1 is 7.4 μg/m^3. Dividing the global unit benefits by this magnitude, we obtain the benefit per person per μg/m^3, whose average for all the cities analyzed ranges from $0.39 to $2.67 US$ per year per person per μg/m^3 for the COI estimates and from $3.30 to $77.10 for the WTP values.

On a city by city basis, the COI unit benefits range from just 1 US cent per person per μg/m^3 (for Tegucigalpa and Managua, LA scenario) to $9 per person per μg/m^3 (Canoas, Brazil, USA scenario). For WTP, the unit benefits range from $0.1 (Tegucigalpa, LA scenario) to $120 (Mendoza, USA Scenario). Obviously, these differences are huge. The average for the whole region for COI values are $0.20 and $3.50/person/(μg/m^3) for the LA and USA scenario respectively, while for WTP values the averages are $2.50 and $68 /person/(μg/m^3) for the same scenarios.

[34] For the E2 scenarios the differences do not reflect the C-R functions, since all cities are assigned the same functions.

Table VII-5 Per Capita Benefits for each city (WTP values)

		US$/person				US$/person/ugm3	
		C1 - 10% reduction		C2 - Annual Standard			
		LAC	USA	LAC	USA	LAC	USA
Type A Cities							
Brazil	Campinas	9	220			2.1	50
	Canoas	9	240			3.7	94
	Cubatao	10	190	21	430	1.5	29
	Porto Alegre	6	210			1.6	55
	Sao Jose Do Campos	6	180			1.7	51
	Sao Paulo	8	190			1.6	37
	Sorocaba	6	200			2.0	62
	Vitoria	4	170			1.3	59
Chile	Calama	6	170	11	310	1.0	26
	Santiago	14	210	45	780	1.8	27
	Temuco	9	210			1.8	44
Colombia	Bogota	7	170	10	270	1.1	28
	Cali	3	130			0.7	29
Jamaica	Kingston	10	170	26	490	1.4	23
Mexico	Guadalajara	11	120	17	190	1.9	20
	Juarez	17	130	54	440	2.3	17
	Mexico City	34	180	70	380	5.4	27
	Monterrey	16	130	26	230	2.6	22
	Puebla	17	150	13	110	3.3	27
	Valle De Toluca	5	82			1.2	19
Panama	Panama City	5	150	16	580	0.6	20
	Average A Cities	**10.0**	**171.5**	**14.7**	**200.5**	**1.9**	**36.5**
Type B Cities							
Argentina	Buenos Aires	35	370	190	2,600	3.0	31
	Cordoba	24	330	110	1,900	2.5	33
	Mendoza	4	230			1.9	120
Brazil	Caxias	12	210	36	700	1.6	28
	Curitiba	9	230			2.8	69
	Itaguai	4	160			1.6	70
	Rio De Janeiro	18	280	68	1,200	2.3	35
	Sao Joao De Meriti	19	250	100	1,700	1.7	22
Costa Rica	Heredia	4	120	15	450	0.6	16
	San Jose	6	160	4	88	1.2	29
Ecuador	Guayaquil	9	140	34	570	1.2	18
	Quito	6	120	10	210	1.1	20
El Salvador	San Salvador	4	97	9	210	0.7	15
Honduras	Tegucigalpa	1	85	3	340	0.1	10
Nicaragua	Managua	1	38	2	70	0.2	6
Peru	Lima	9	140	54	960	0.6	10
Uruguay	Montevideo	57	500	370	4,700	3.6	31
Venezuela	Caracas	9	150			2.1	35
	Average B Cities	**12.8**	**200.6**	**55.8**	**872.1**	**1.6**	**33.2**
	Average All cities	**11.3**	**184.9**	**33.7**	**510.5 #**	**1.8**	**35.0**

Table VII-6 Per Capita Benefits for each city (COI values)

		US$/person				US$/person/ugm3	
		C1 - 10% reduction		C2 - Annual Standard			
		LAC	USA	LAC	USA	LAC	USA
Type A Cities							
Brazil	Campinas	0.8	19			0.19	4.6
	Canoas	0.8	22			0.33	9.0
	Cubatao	0.9	28	2.0	59	0.15	4.4
	Porto Alegre	0.5	11			0.14	3.1
	Sao Jose Do Campos	0.5	16			0.16	4.6
	Sao Paulo	0.8	11			0.16	2.2
	Sorocaba	0.6	14			0.18	4.7
	Vitoria	0.3	9			0.12	3.1
Chile	Calama	0.6	17	1.0	29	0.09	2.8
	Santiago	1.1	16	3.8	49	0.15	2.1
	Temuco	0.7	19			0.15	4.1
Colombia	Bogota	0.6	18	0.8	28	0.09	3.2
	Cali	0.2	8			0.06	1.9
Jamaica	Kingston	0.7	15	2.0	40	0.11	2.2
Mexico	Guadalajara	0.7	13	1.0	20	0.11	2.3
	Juarez	1.2	32	4.0	97	0.17	4.4
	Mexico City	2.1	23	4.4	47	0.34	3.7
	Monterrey	1.1	26	1.9	43	0.19	4.4
	Puebla	1.2	24	0.9	18	0.22	4.5
	Valle De Toluca	0.4	10			0.09	2.3
Panama	Panama City	0.4	11	1.4	37	0.05	1.5
	Average A cities	**0.8**	**17.2**	**1.1**	**22.2**	**0.2**	**3.6**
Type B Cities							
Argentina	Buenos Aires	2.6	48	15.0	230	0.23	4.2
	Cordoba	1.7	31	8.2	130	0.18	3.3
	Mendoza	0.3	6			0.14	3.2
Brazil	Caxias	1.0	27	3.2	80	0.14	3.8
	Curitiba	0.8	21			0.25	6.7
	Itaguai	0.3	9			0.14	4.1
	Rio De Janeiro	1.5	30	5.7	100	0.19	3.8
	Sao Joao De Meriti	1.7	41	9.3	190	0.15	3.8
Costa Rica	Heredia	0.3	10	1.1	31	0.04	1.3
	San Jose	0.4	12	0.3	7	0.08	2.2
Ecuador	Guayaquil	0.6	17	2.3	57	0.08	2.2
	Quito	0.4	12	0.7	20	0.07	2.1
El Salvador	San Salvador	0.3	11	0.7	21	0.05	1.7
Honduras	Tegucigalpa	0.1	3	0.3	9	0.01	0.4
Nicaragua	Managua	0.1	2	0.1	3	0.01	0.3
Peru	Lima	0.7	25	4.6	120	0.05	1.8
Uruguay	Montevideo	4.2	58	27.0	300	0.27	3.9
Venezuela	Caracas	0.6	18			0.15	4.2
	Average B cities	**1.0**	**21.2**	**4.4**	**72.1**	**0.1**	**2.9**
	All Cities	**0.9**	**19.0**	**2.6**	**45.3 #**	**0.1**	**3.3**

VII.C.4 Summary Benefits

Finally, table VII-7 shows a summary of the total and per capita benefits for all the cases analyzed, separated by the type of city, as well as the benefits expressed as percentage of the total income of the cities.

Table VII-7 Summary of total benefits (a) , per capita benefits (b), and benefits as percentage of income (c), by city type

(a) Total benefits (MUS$/year)

Benefits	Scenario	C1 - 10% reduction			C2 - Annual Standard		
WTP							
	LAC	1,100	670	**1,700**	1,900	3,300	**5,200**
	USA	11,000	8,900	**20,000**	16,000	49,000	**66,000**
COI							
	LAC	73	52	**130**	130	260	**390**
	USA	1,100	1,100	**2,200**	1,800	4,400	**6,200**

(b) Per capita benefits (US$/person/year)

Benefits	Scenario	C1 - 10% reduction			C2 - Annual Standard		
WTP							
	LAC	17	18	17	44	103	70
	USA	175	245	201	374	1,531	883
COI							
	LAC	1	1	1	3	8	5
	USA	17	30	22	42	137	83

(c) Benefits as Percentage of Income (%)

Benefits	Scenario	C1 - 10% reduction			C2 - Annual Standard		
WTP							
	LAC	0.3%	0.5%	0.4%	0.8%	2.9%	1.4%
	USA	3.3%	6.5%	4.3%	6.4%	43.4%	18.1%
COI							
	LAC	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%
	USA	0.3%	0.8%	0.5%	0.7%	3.9%	1.7%

VIII. CONCLUSIONS

This paper has provided a number of pieces of evidence highlighting the importance of air pollution from the perspective of public health and economic burdens, not just environmental quality in some more general sense. However, the size of the problem depends on some key judgments about uncertainties in scientific knowledge and about environmental conditions. In this concluding section of the paper we seek to summarize and put in a broader context the many findings flowing from our analysis, including their potential implications for air quality policy.

The first point concerns simply what we know about air quality itself. This comprehensive survey of available air quality data indicates that 26 cities, containing 85 million people (of which 28 million are children less than 18 years of age) out of the almost 100 million population of the cities considered in the study, are exposed to particulate concentrations above internationally accepted levels. For many of them (18 million, 6 of them children), the excess is notably large (more than twice the US standard). We must also note, however, that for many of the cities we have considered, particulate data are of very uncertain quality. For almost all cities, moreover, data on ground level ozone or its precursors is very elusive. Based on the general principle that good policy flows from good data as well as sound analysis, improvement in air quality monitoring in Latin America should be a higher priority than it evidently is at the present time.

The physical effects on health of these excess pollution levels also are quite significant. If we look only at cities with PM concentrations above the standard, reducing concentrations to the level of the standard would avoid on the order of 10,500 to 13,500 premature deaths as well as well a host of illness incidents, reduced activity days, and lost productivity. The premature deaths avoided from this air quality improvement would occur across the age distribution but would be especially important for more sensitive elder and child populations (by some of our estimates, 10,000 and 2,500 excess deaths avoided in these groups, respectively). The total premature deaths avoided would be on the order of 2 to 2.6% of total deaths per annum in the cities considered.

Benefits occur not just from reducing PM concentrations to meet the US standard but also through further improvements below the standard, since the standard does not reflect a physical threshold. Our other simulation of air quality improvement involved a 10% reduction in concentrations in all cities. This also led to large reductions in morbidity impacts and premature mortality, with benefits spread out over the range of cities. Indeed, for this scenario the deaths avoided in cities meeting the standard are 12 to 25% of total deaths avoided, suggesting that just meeting the standard should not automatically be seen as an adequate goal

These relatively significant benefits are predicted whether one relies on epidemiological studies from Latin America or on extrapolated application of US-based studies – the latter actually predict even larger health improvements, on the order of 30% more. The disparities across studies and gaps in knowledge do indicate a benefit of improved public health analysis for Latin America. But from the perspective of economic benefits analysis for air quality, this link may be less in need of improvement than the air quality data themselves, or the economic valuations of avoided impacts.

The benefits we estimated contain considerable uncertainty that stems from the concentration levels in the cities, from the epidemiological studies used to compute the physical impacts, and from the unit values used to finally value the impacts. There is no direct way to quantify the uncertainty from the concentration levels in the cities analyzed. We have presented the results for the cities separated by our assessment of the quality of the concentration data. To reduce this uncertainty, monitoring networks need to be improved, both in terms of number of monitors as well as the time resolution of the measurements and reporting of this information. Right now, many agencies report only annual averages, without explication of the finer temporal detail actually produced by the monitors.

Assuming the ambient concentrations of the cities are relatively well estimated, we estimated the benefits of different reductions using two different sources, Latin America (LAC) and the USA, for both epidemiological and valuation studies. These two sources produce benefits estimates that differ by a factor of approximately 12 for WTP estimates, and 17 for COI estimates. This huge difference stems mainly from the difference in unit values. For example, for mortality benefits (which are the biggest contributor to benefits, and also the easier to compare) mortality risk reduction benefits from the USA data are about 11 times the ones based on LAC data, while the number of cases are only 30% more. For morbidity benefits, a direct comparison is difficult due to the different endpoint and age group coverage of LAC and USA studies, but this very difference in coverage is responsible for most of the difference between the two scenarios.

These results suggest that more research in LAC is needed in both the estimation of impacts and on the valuation of them. For health impacts, the main emphasis would need to be on morbidity endpoints, for which there are still few data. For valuation, the most important component is the willingness to pay to reduce risks of death.

Although isolated research is probably being conducted at this moment, we are aware of two more broad projects that are being carried out. One is a multi-country study sponsored by the Health Effects Institute, which aims to assess the short-term mortality impacts applying a uniform method in several LAC cities. This would provide consistent estimates which may improve the estimation of premature deaths in the region. The second initiative is to apply the contingent valuation survey of Krupnick, Cropper, Alberini and Simon (Krupnick, Alberini et al. 2002) in countries around the world, such as China, Japan, some European countries, the U.S. and Canada. While an early version of this survey has been applied in Santiago, no further work with this survey is on-going in LAC. However, the Colombian government is considering mounting this survey.

In turning to the valuations, we note that our findings are sensitive to the measure used for valuing health improvements. Economic analysis makes a solid case for use of the broader and more inclusive "willingness to pay" measure relative to the cost-of-illness measure – the more intangible elements included in the former, related for example to discomfort and benefit from mortality risk reduction, are as much a part of social welfare as medical and productivity costs. But they will not register in the national accounts, for example, and with scarce resources there may be some pressure in the policy process to scale investments in air pollution control to the more modest level implied by cost of illness assessments of benefits.

Even this more limited measure is nontrivial if we use the more inclusive US COI figures, which while transferred from outside Latin America reflect more impacts than comparable Latin American figures. According to our analysis, about $2.2B or $6.2B per annum in COI benefits might be realized, depending on the pollution control scenario. Such figures could justify significant investments in pollution control as a form of public health protection.

If one does accept WTP for the benefits measure, then uncertainties regarding unit valuations need to be addressed. If we use results based only on Latin American health and valuation assessments, we get values of $1.7 or $5.2 B depending on pollution control scenario. These represent roughly 0.4-1.4% of income averaged over all the cities, a nontrivial valuation by any measure. This is a large enough figure to potentially justify significant pollutant control measures.

While the transfer of US WTP values for mortality risk reduction also is subject to much uncertainty, including uncertainty about the US mortality risk reduction benefits themselves, we have confidence in the procedure we have used, which implies a WTP value that is a larger share of income than in the US. If we combine the transferred US unit values with health impacts also predicted by US studies, the benefits results are roughly *12 times* larger than what we get using only Latin American based information. These larger numbers provide yet more basis for policy intervention to improve air quality – again, on economic and public health grounds.

Notwithstanding the range of estimates we present and the largely unquantifiable uncertainties excluded from this range, the results provide a call to action for controlling urban air pollution in Latin American cities. What forms this action should take is not the subject of this paper. However, in Santiago Chile, where cost benefit assessment has been used to screen air quality improvement options, benefits information of the type we have generated has been used with cost information to lay out a menu of potential interventions. These include new emission standards for fixed and mobile sources (new buses, trucks, and automobiles), the retrofit of existing diesel vehicles with particle traps, the introduction of very-low sulfur diesel fuel, street cleaning programs, and the introduction of an emissions cap and trade system to improve efficacy and cost-effectiveness of emissions limitations for fixed sources. The results of the CBA informed policy making, shifting the priorities toward the measures with higher benefit/cost ratios (CONAMA R.M. 2001). However, these benefits were not the only input that policy makers considered. Otherwise, policies for which the B/C ratio was less than one (like street cleaning) would not have been implemented.

In studies of US benefits and costs of air quality improvement, total benefits generally dwarf total costs of action – though the same is not true in all cases of *incremental* costs and benefits (EPA 1997; EPA 1999). In Latin America the benefits values, while larger relative to income, still are not so large as to justify *a priori* any conceivable intervention. The cost-effectiveness of different interventions is sector and country-specific. Generally, simple PM filtration measures at stationary sources can be cost effective, as can be some targeted measures to reduce emissions from older diesel vehicles or to introduce low sulfur diesel fuel. How far these and other interventions can be taken while still yielding net benefits – and widely shared benefits – requires more detailed analysis of mitigation costs. What our analysis may offer from a policy perspective, among other points, is a stronger rationale for investigating policy options and then robustly implementing those policies that can be justified.

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