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# Short-term improvements in public health from global-climate policies on fossil-fuel combustion: an interim report

*Working Group on Public Health and Fossil-Fuel Combustion**


## Summary

**Background** Most public-health assessments of climate-control policies have focused on long-term impacts of global change. Our interdisciplinary working group assesses likely short-term impacts on public health.

**Methods** We combined models of energy consumption, carbon emissions, and associated atmospheric particulate-matter (PM) concentration under two different forecasts: business-as-usual (BAU); and a hypothetical climate-policy scenario, where developed and developing countries undertake significant reductions in carbon emissions.

**Findings** We predict that by 2020, 700 000 avoidable deaths (90% CI 385 000–1 034 000) will occur annually as a result of additional PM exposure under the BAU forecasts when compared with the climate-policy scenario. From 2000 to 2020, the cumulative impact on public health related to the difference in PM exposure could total 8 million deaths globally (90% CI 4·4–11·9 million). In the USA alone, the avoidable number of annual deaths from PM exposure in 2020 (without climate-change-control policy) would equal in magnitude deaths associated with human immunodeficiency diseases or all liver diseases in 1995.

**Interpretation** The mortality estimates are indicative of the magnitude of the likely health benefits of the climate-policy scenario examined and are not precise predictions of avoidable deaths. While characterised by considerable uncertainty, the short-term public-health impacts of reduced PM exposures associated with greenhouse-gas reductions are likely to be substantial even under the most conservative set of assumptions.


*Lancet* 1997; **350**: 1341–49

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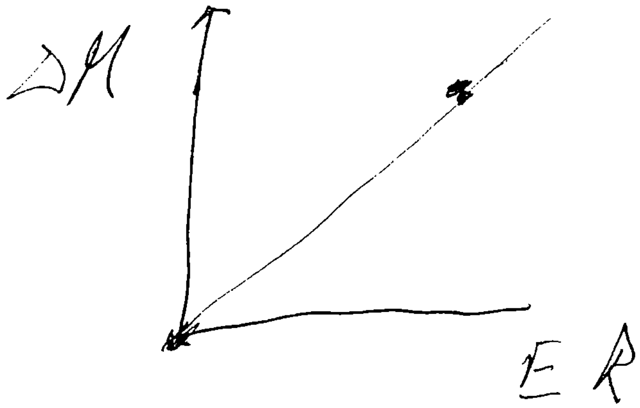
## Introduction

Since the industrial revolution, the contribution of anthropogenic sources of greenhouse gases to the global environment has increased significantly.[1] Atmospheric concentrations of greenhouse gases, including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), are of greater importance today than at any other time in human history. These trends can be largely attributed to human activities, primarily fossil-fuel combustion, and change in land use and agricultural practices. In the absence of efforts to reduce greenhouse gases, the concentrations of these gases are expected to grow significantly throughout the next century. The mid-range estimate from the Intergovernmental Panel on Climate Change (IPCC) is that human-induced climate-change will increase surface temperatures by about 2°C by the year 2100;[2] many uncertainties exist about this projection.

In an effort to protect the global-climate system for future generations, over 150 nations signed the UN Framework Convention on Climate Change (UNFCCC) in June, 1992.[3] The UNFCCC established the objective of stabilising atmospheric greenhouse-gas concentrations at levels that would avoid dangerous anthropogenic interference with the global-climate system. Signatory countries will be considering options to control greenhouse gases at the third conference of parties in Kyoto, Japan, in December, 1997.

Short-term public-health impacts have generally not been considered in assessments of global-climate change. Two studies,[4,5] for example, have projected that well into the next century, weather patterns resulting from climate change are expected to affect the health of future generations. Heat-related mortalities and illnesses, physical and psychological traumas, and changes in vector-borne and infectious diseases, food supplies, and coastal sea-levels are expected to become evident. With various models, we estimate likely public-health benefits of current and future global-climate-change mitigation policies in the first two decades of the 21st century in developed and developing countries.

Many of the fossil-fuel combustion processes that produce $CO_2$ and other greenhouse gases also produce a host of air pollutants such as particulate matter (PM), sulphate, ozone, and other pollutants, all of which have short-term adverse effects on public health. We use PM as a sentinel air pollutant because it is commonly associated with fossil-fuel combustion. Extensive public-health literature in several countries has shown that both mortality and morbidity are significantly associated with exposure to PM.[6,7] Most air pollutants from fossil fuels have local impacts but some airborne pollutants (eg, fine particulates) can be transported thousands of miles and have global impacts.[8]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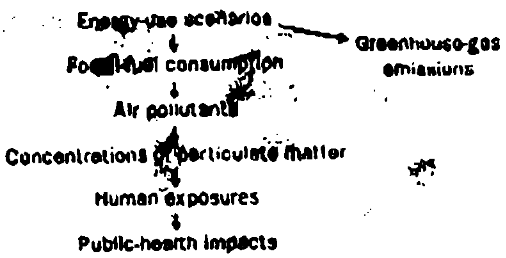


**Figure 1: Models used in estimating the global impact of fossil-fuel consumption on public health**

We combined analyses from several independent models of energy consumption (to provide a first approximation of likely $CO_2$ emissions), associated concentrations of PM, and probable increases in mortality associated solely with PM by the year 2020 (figure 1). This analysis presents a scenario-based order-of-magnitude estimate of the possible size of the air-pollution impacts on populations in developed and developing countries.

## Methods

### *Scenario development*

Estimation of the consequences for public health of projected global events requires the development of scenario-based impact assessment that relies on complex models of environmental change.[9] Our study develops two possible $CO_2$ emission scenarios: a business-as-usual (BAU) scenario which updates IPCC's 1992 analysis of expected trends in energy consumption and associated $CO_2$ emissions;[10] and a hypothetical climate-policy scenario, which considers the stated intentions of the European Union regarding proposed reductions in $CO_2$ emissions for developed countries,[11] coupled with additional measures by developing countries. Under our hypothesised climate-policy scenario, developed countries would undertake concerted and binding efforts to reduce energy-related $CO_2$ emissions 15% below 1990 levels by the year 2010. Under this same climate-policy scenario, developing countries are assumed to reduce their emissions 10% below their levels of greenhouse-gas emissions forecast for 2010—that is, 10% below what would otherwise be their BAU trends by 2010. This is consistent with agreements made by developing countries under the Berlin Mandate to advance implementation of existing commitments to promote technologies, practices, and processes that reduce greenhouse-gas emissions.

BAU updates IPCC →

Climate Scenario

timing

Both these scenarios assume that total energy use and efficiencies in the developing countries continue to increase to meet the needs of economic growth. The differences between them lie in the rates of growth in energy use, the fuel mixes, and their combustion and end-use efficiencies. Under each of these scenarios, emissions of PM are taken as representative of general ambient air pollution associated with fossil-fuel combustion and $CO_2$ emissions. Based on projected concentrations of PM, we estimate annual and cumulative numbers of avoidable deaths in the years 2010 and 2020 among adults aged over 30 years and infants of up to 1 year in developed (annex 1) and developing (non-annex 1) countries (UNFCCC nomenclature). Avoidable deaths refers to the estimated annual premature mortality associated with PM from modelled fossil-fuel combustion (ie, attributable risk) that could be avoided by adopting the hypothesised climate-policy scenario. Because the aerodynamic size of the particles produced is of great importance, our model estimates the emissions and concentrations of particles that are less than 10 μm ($PM_{10}$) and fine particles of less than 2·5 μm ($PM_{2.5}$). A host of other adverse acute and chronic health effects are also associated with PM and other air pollutants, but are not analysed here.[1,12]

PM derives from fossil fuel use

older adults & infants

PM 10 & PM 2.5

### *Fossil-fuel consumption and carbon emissions*

Future fossil-fuel consumption and resulting emissions of greenhouse gases and other air pollutants reflect complex interactions of several key variables, including economic activity, transportation modes, demographic trends, the rate and nature of technological innovations, and energy prices. The IPCC devised six well-documented projections of greenhouse-gas emissions in 1992.[10] The IPCC used the Atmospheric Stabilisation Framework (ASF) model to relate socioeconomic scenarios to carbon emission trajectories. The ASF model contains detailed representations of fossil-fuel consumption for four sectors (electric utility, residential/commercial, industrial, and transportation) for nine global regions.

ASF model

All $CO_2$ emission estimates in this paper refer to emissions attributable to the combustion of fossil fuels, which represent about 75% of current global anthropogenic emissions of $CO_2$.[13] The $CO_2$ emission projections presented in this paper fall within the range of other emission projections documented in the literature. The 8·3 billion metric tonnes of carbon (BMTC) from fossil-fuel combustion presented in this paper for 2010 is slightly lower than the estimate of 8·8 BMTC as predicted by Energy Information Administration.[14] Our 2020 projection of 10·7 BMTC is higher than the IIASA/WEC projection of 8·4 BMTC[15] and similar to the Shell Oil sustained-growth scenario estimate of 10·5 BMTC.[16]

carbon only

BAU diff's from EIA

The input in this study has been updated to reflect more recent population projections, the breakup of former Soviet Union, and lower anticipated fossil-fuel prices. The model assesses $CO_2$ emission-reduction goals, by choosing the most efficient and least cost emission-reduction opportunities available in each region, and recognises efficiency improvements in many developing countries.[17] The global-population data used for these scenarios are consistent with the World Bank's medium-growth assumptions.[18] The gross national product (GNP) growth assumed for the BAU scenario is slightly higher than the one used in the IS92a scenario, which reflects several economic, energy, and climate-change-related studies.[19,20]

least cost derivation of fuel-switching

GNP ↑ higher than IS92a

Table 1 and figure 2 indicate several trends and associations of fossil-fuel consumption patterns modelled under both the BAU and climate-policy scenarios. In 1990, despite having only 24% of the world's population, annex 1 countries accounted for 70% of global fossil-energy consumption and 68% of carbon emissions from fossil fuels. Under BAU, overall growth in $CO_2$ emissions from annex 1 countries is relatively moderate through the projection period, 1990–2020, rising by only 17·5% through 2020. This moderate growth may be explained by current trends of fossil-fuel consumption patterns in Russia and the former Soviet Union. These regions

17.5% BAU growth in A1

| | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | | 2010 | | | | 2020 | | | |
| | A1 | NA1 | BAU A1 | BAU NA1 | CP A1 | CP NA1 | BAU A1 | BAU NA1 | CP A1 | CP NA1 |
| **Fossil fuel** | | | | | | | | | | |
| Coal | 58 | 38 | 80 | 75 | 31 | 82 | 44 | 100 | 31 | 78 |
| Oil | 92 | 41 | 110 | 99 | 94 | 97 | 118 | 152 | 95 | 180 |
| Natural gas | 59 | 12 | 66 | 35 | 64 | 35 | 77 | 64 | 71 | 64 |
| Total fossil-fuel use | 209 | 91 | 226 | 209 | 189 | 194 | 239 | 316 | 197 | 290 |
| **Carbon emission** | | | | | | | | | | |
| Billion metric tonnes (BMTC) | 4 | 1·9 | 4·2 | 4·1 | 3·4 | 3·7 | 4·7 | 6 | 3·4 | 5·4 |
| Relative carbon emissions | 68% | 32% | 51% | 49% | 48% | 52% | 44% | 56% | 39% | 61% |

A1=developed (annex 1) countries; NA1=developing (non-annex 1) countries; BAU=business as usual scenario; CP=climate-policy scenario.

**Table 1: Fossil-fuel energy use ($10^{18}$ J) under business-as-usual and climate-policy scenarios**

Why A1 BAU won't grow more

markedly differ from other annex 1 countries, in that sharp declines in energy consumption are not assumed to reach 1990 levels again before 2020. As a consequence, future increases in emissions in annex 1 countries under the BAU scenario are masked by these reduced consumption patterns in Russia and the countries of the former Soviet Union.

NA1 BAU growth is 116%

The expected growth in energy-related $CO_2$ emissions of non-annex 1 countries under BAU by 2020 exceeds the total level of emissions of annex 1 countries in 1990. Non-annex 1 countries' carbon emissions resulting from consumption of fossil fuels are expected to rise from 1·9 BMTC in 1990 to 4·1 BMTC in 2010, a 116% increase over 30 years. In 1990, annex 1 countries produced 68% and non-annex 1 countries produced only 32% of total global carbon emissions. Under the BAU scenario, by the years 2010 and 2020, non-annex 1 region's projected contributions will be 4·1 and 6 BMTC, respectively. On the other hand, if the climate-policy scenario is implemented, by the years 2010 and 2020, non-annex 1 region's projected carbon emissions could be reduced to 3·7 and 5·4 BMTC, respectively. Figure 2 shows the relative contributions of developed and developing countries to fossil-fuel use for the years 1990, 2010, and 2020 under both scenarios. The global fossil-fuel consumption is expected to be less under the climate policy scenario, which reflects increased fuel-combustion efficiencies, conservation measures, and improved technologies. We assume that there is no cross-border trading of greenhouse gases. Under the climate-policy scenario, $CO_2$ emissions decrease more than fossil-fuel consumption as countries switch away from coal to less polluting fuels, such as natural gas.

No trading

### *Pollutant emissions and concentrations*

The following discussion outlines the modelling protocol followed in this study along with a brief description of key assumptions and sensitivity analyses.

source-receptor

A PM source-receptor matrix[21] was used to derive concentration patterns for $PM_{10}$ and $PM_{2.5}$ per unit of energy use for each of the four sectors and three fossil-fuel types (coal, oil, and natural gas). The source-receptor coefficients were calculated with large-scale air-dispersion models that were based on emission inventories calibrated with and matched to extensive monitoring data in USA for 1990–1994.[14] In addition to calculation of concentrations of primary particles (those emitted directly by sources), the model also incorporates the secondary conversion of gaseous precursors ($SO_2$ and $NO_x$) to fine particulates as they are transported through the lower atmosphere. The source-receptor-matrix model yields smoothed, area-wide averages of $PM_{10}$ and $PM_{2.5}$ concentrations for each IPCC region and does not estimate local airborne-pollutant levels at specific receptor sites; the latter air-pollutant estimates are generally calculated with Gaussian air-dispersion models that incorporate only local emission inventories and meteorological data. To do this analysis, we assume that airborne fine particles travel hundreds of miles through the atmosphere and their estimated regional concentrations are not very sensitive to the details of the modelling matrix. This contrasts with the well-known difficulty of modelling for short-term ozone episodes over a small geographic area. Evidence supporting the long-range transport of fine particles can also be found—eg, in

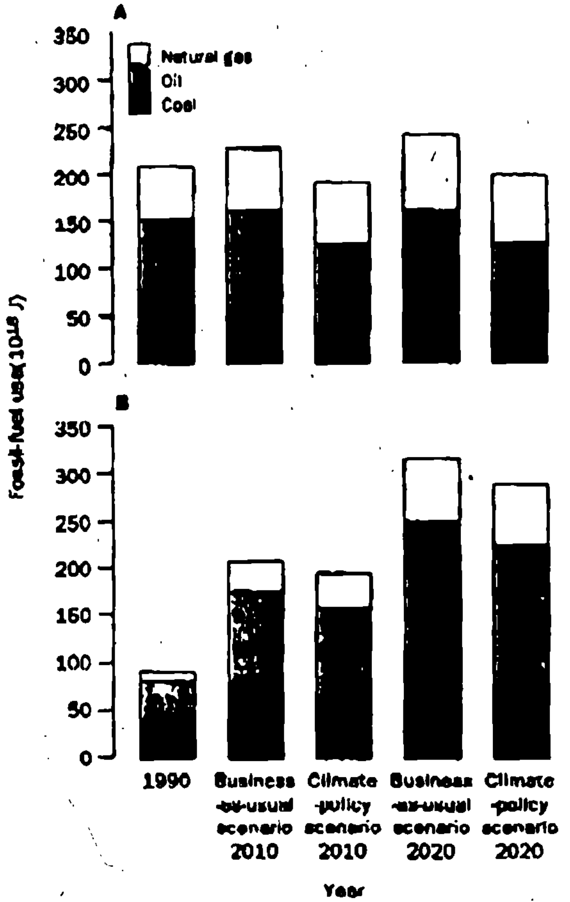


**Figure 2: Fossil-fuel use under business-as-usual and climate-policy scenarios in developed (annex 1; A) and developing (non-annex 2; B) countries**

the report of the second World Meteorological Organization meeting of experts to assess the response to and atmospheric effects of the Kuwait oil fires.[23]

Applying such a large-scale air-dispersion model carries with it several assumptions that could result in a misestimation of actual PM concentrations. In the absence of data on typical chimney heights in other parts of the world, for example, we have assumed that the distribution of chimney heights in the USA is representative of that found elsewhere. Should average heights of chimneys in a given region be lower than in the USA, the likely consequence would be higher local concentrations of particles and their precursors, and lower concentrations at greater distances downwind. Conversely, higher chimneys could yield lower concentrations near a given source but higher concentrations further downwind. A second key assumption is that the spatial association between emission sources and population densities in the USA is representative of the rest of the world. In some developing regions, such as the mega-cities of Southeast Asia, whose population patterns are more geographically dense, this approach is likely to underestimate actual human exposures to airborne pollutants. Also, the source-receptor-matrix model makes no estimates of indoor air-pollutant exposures to PM from coal or biomass used for cooking and heating. Such exposures are known to be very high in several developing regions, such as China, Africa, and India.[24]

Our modelling indicates that concentrations of PM from a fixed quantity of emissions in hot and dry regions are about one-third of what would be expected from those same emissions under most other climatic conditions. The likely reasons for this are: higher ambient temperatures coincide with greater mixing heights, hence a greater volume of air for dispersion; and the conversion of gaseous PM precursors such as $SO_2$ into intermediate products (sulphuric acid) requires the presence of water vapour. Where less water vapour is available, conversion rates are slower and conversion takes place over longer distances. Therefore, regional levels of PM are expected to be lower in dryer climates.

To capture these influences of climate on PM concentrations, the USA was divided into four roughly equal geographic zones based on long-term climatic data: hot/dry, hot/wet, cold/dry, and cold/wet. Unique source strengths for each sector/fuel were derived for each zone. Similar climatic data for each of the remaining eight global regions were used along with data on population densities to obtain the appropriate, representative weighting among USA climate zones—eg, 90% of the population of the Southeast Asia group was found to reside in a climate which most closely resembles the hot/wet designation, while 10% resides in a hot/dry grouping; none was in the cold/dry or cold/wet zones. To derive an overall Southeast Asia estimate, the source-receptor association for the hot/wet USA zone was weighted 90%, and the hot/dry zone 10%. Had we not adjusted the source-receptor matrix to account for regional differences for climate, and instead used the USA climate as a proxy for the rest of the world, then the modelled concentrations of PM would have been from 16% (climate policy Asia) to 130% (climate policy Europe) lower.

This analysis projected future global patterns of energy consumption and adjusted the overall USA source-receptor association to account for climate differences in other global regions. To project likely changes in concentrations of PM, it is also necessary to estimate future efficiencies of pollution-control equipment and policies unrelated to climate-control mitigation. In our analysis, two alternative pollution-control strategies were assumed to occur, in developed and developing regions. The USA Organisation for Economic Co-operation and Development (OECD)-West and OECD-Asian countries were assumed to use USA controls, including $SO_2$ and $NO_x$ controls outlined in the USA, 1990, Clean Air Act. These do not reflect controls that individual states of the USA might adopt as a result of recent revisions to ozone and PM National Ambient Air Quality Standards, which are not expected to go into effect until after the adoption of climate-change mitigation strategies. All other regions were assumed to start with no controls in the year 2000. By the year 2020, these other regions were assumed to attain 1990 USA control levels for transportation-related emissions and 1970 USA control levels for point-source emissions.

LDC pollution red. Baseline

Our results are sensitive to the estimation of pollution-control efficiencies for fuel combustion because emission rates change in relation to these values. This is especially true for situations where high levels of control are estimated, because the difference between 90% and 99% control is a ten-fold difference in emissions. For countries that may have more stringent control programmes than the USA (eg, certain sectors in Japan), use of USA standards as a proxy may overestimate future PM concentrations. It is also possible that our assumptions about future pollution-control efficiencies are too optimistic for developing countries; if so, then we will have underestimated emissions and associated health effects of the control scenarios. The sensitivity of the analysis to assumed control levels was evaluated by calculating PM concentrations in non-annex 1 regions and Eastern Europe and former Soviet Union, which would result in the absence of controls. Analysis for 2020 showed that removing controls would yield $PM_{10}$ and $PM_{2.5}$ concentrations of 65% and 32% higher, respectively, than the values calculated in the BAU analysis.

Further refinements to transportation-related emissions in all non-USA regions were made to account for the much higher reliance on diesel fuel in most of the world than in the USA.[illegible] The fraction of the energy consumed in the transportation sector which is diesel fuel is different in each country (eg, 60% in Latin America, 20% in the USA) and the fraction is assumed to remain constant throughout the study period. These refinements also assume a steady reduction in use of lead in petrol starting from present levels in the year 2000 to zero in 2010. Increased use of catalytic converters to control vehicle-exhaust pollutants will accompany phase-out of lead.

In the USA, data indicate that ambient $PM_{10}$ concentrations are on average 65% of total suspended particulate concentrations; $PM_{2.5}$ concentrations are on an average about 50% of $PM_{10}$ concentrations; and fossil-fuel combustion accounts for about 45% of measured $PM_{2.5}$ concentrations.[illegible] To validate modelled PM concentrations, ambient monitoring data were gathered for about 40 countries. Virtually all of the data, however, were for total suspended particulate and no data were found which established the fractional contribution from fossil-fuel combustion. If one were to assume that the percentage of total suspended particulate that is contributed by fuel-combustion sources in the USA holds throughout the world, then estimated PM concentrations should be two to ten times higher than those developed in this study. In our judgment, it is highly unlikely that other regions experience long-term average PM concentrations from fossil-fuel combustion that approach such levels. Total suspended particulate concentrations in most of the world are at least twice as high as those in the USA; this is likely due to factors such as much higher contribution to the coarser fraction (>2·5 μm) from such sources as wind-blown dust (eg, Middle East) as well as a higher fine fraction (<2·5 μm) contribution from sources such as biomass burning from heating, cooking, and forest clearing (eg, Southeast Asia).

*Health-impact estimates*

Extensive public-health literature in several countries shows that both mortality and morbidity are significantly associated with exposure to PM.[4,5] Besides mortality, studies in several countries have associated PM with cardiovascular and respiratory morbidity (eg, increased hospital admissions and emergency-room visits for acute and chronic pulmonary effects, including bronchitis, asthma, cough and wheeze).[5,7,29] Little is known about the mechanism of action of PM. Some toxicological studies have produced bronchitic responses,[30] arrhythmias,[31] and exacerbation of pneumonia in rats[32] from exposure to fine particles, which are similar to those observed in epidemiological studies. It has been found that tiny respirable particles or airborne aerosols can interfere directly with pulmonary function and plasma viscosity in animals and human beings.[33-35] Mortality effects have consistently been associated with short-term and long-term exposure to PM in more than 40 studies done in over ten countries.[4,7,24,36]

The short-term exposure studies use daily time-series analysis to assess changes in mortality in the general population that are associated with changes in daily concentrations of PM. Long-term exposure studies of PM have used a prospective cohort design, which allows the adjustment of potential confounders in the assessment of the association between PM and mortality.

Health benefits from reductions in PM have been derived previously from epidemiological studies done in the USA and in Europe.[38,39,40] Long-term exposure studies were used as the basis for the quantitative analysis because the results from these analyses have followed single cohorts and adjusted for important confounders. These analyses suggested mortality effects from both long-term and short-term exposure to PM.[4,24,41] Epidemiological studies were chosen for this quantitative analysis only if they reported the relative risk (RR) as a monotonic function of PM concentrations. The two age groups for which RR has been estimated in long-term studies are adults aged over 30 years and infants aged between 1 month and 1 year. To evaluate the impact of PM concentrations on adult mortality, the paper by Pope and colleagues was selected as the basis for quantitative analysis.[42] For infant mortality, we used a study by Woodruff and colleagues[43] that reported RR as a continuous monotonic function of PM concentrations. Pope and colleagues found that a 24·5 μg/m³ increase in $PM_{2.5}$ is associated with a 1·17 (95% CI 1·09–1·26) increase in RR of total mortality for adults over 30 years. Woodruff and colleagues, found that for a 10 μg/m³ increase in $PM_{10}$, an odds ratio of 1·04 (95% CI 1·02–1·07) for increases in total infant mortality between 1 month and 1 year associated with increases in $PM_{10}$ concentrations.

We assume that the association is the same in the rest of the world as it is in the USA. Epidemiological studies have found a relatively consistent association between short-term exposures to PM and mortality in many countries, including Chile, Brazil, and Western Europe.[4,37] Given the relatively consistent association found between short-term exposure to PM and mortality across countries, it is reasonable to assume that the health effects from long-term exposures to PM in other regions of the world parallel those of the USA.[*]

The association between change in $PM_{2.5}$ and $PM_{10}$ and change in mortality risk is modelled as an exponential function. The exponential functional form for the RR comes from the specification of the logistic regression model used in the study by Woodruff and colleagues, and the Cox's proportional hazard model used in the Pope study for evaluation of the association between PM and mortality. In this model, the RR associated with a PM change of Δ PM is:

$$RR(PM) = \exp(\beta \, \Delta PM)$$

The slope coefficient, β, is derived from the chronic-exposure epidemiological studies selected for use in this analysis, and Δ PM is the incremental change in the annual mean (or median) PM concentration, had a policy-based scenario not been adopted. The risk reduction associated with adoption of the policy is:

$$[\exp(\beta \, \Delta PM)-1].$$

The estimated regional incidence of avoided premature mortality is:

$$\Delta \text{mortality}=(RR\,[\Delta PM]-1)\ (\text{mortality rate})\ (\text{population}),$$

where the mortality rate and population are the adult or post-neonatal regional estimates, derived from projections of population by age and infant mortality rates by country. These were obtained from the Bureau of Census (USA) international database and aggregated to a regional level. The projected baseline age-adjusted regional adult (>30 years) mortality rates were calculated from individual country population projections (by 5-year age group), adjusted for immigration and emigration with World-Bank projected net-migration rates.

The source-receptor-matrix estimates annual mean PM concentrations. The RRs in the Pope study are based on the annual median of daily PM concentrations, which is usually lower than the mean for air-pollution concentrations.[44] PM data, from the USA, suggests that a γ distribution best describes the observed skewed distribution of daily PM levels.[45] Assuming a γ distribution, an estimated median can be derived from the mean and an estimated maximum daily level. Observed population-weighted peak-to-mean ratios from four USA geographic zones are applied to the source-receptor association. A maximum likelihood routine was used for each region in the climate-policy scenario to estimate the γ distribution with the estimated mean and maximum daily level.

## Results

The scenarios that form the basis for this exercise rest on complex models of energy-use trends, estimated emissions of carbon, projected levels of PM, and associated impacts on mortality. Each of these models

| Year | Annex 1 | Non-annex 1 | Total |
|---|---|---|---|
| 2000 | 0 | 0 | 0 |
| 2005 | 56 000 (31 000–83 000) | 137 000 (75 000–204 000) | 193 000 (106 000–287 000) |
| 2010 | 69 000 (48 000–131 000) | 288 000 (167 000–425 000) | 376 000 (206 000–557 000) |
| 2015 | 108 000 (60 000–156 000) | 508 000 (278 000–750 000) | 614 000 (337 000–906 000) |
| 2020 | 138 000 (76 000–203 000) | 563 000 (309 000–831 000) | 701 000 (385 000–1 034 000) |
| Total cumulative* avoided mortality 2000–2020 | 1 670 000 (900 000–2 500 000) | 6 340 000 (3 500 000–9 400 000) | 8 010 000 (4 400 000–11 900 000) |

*Cumulative is sum of annual deaths each year between 2000 and 2020. A1=annex 1 (developed) countries; NA1=non-annex 1 (developing) countries.

**Table 2: Annual avoided mortality with 90% CIs (combined adult and neonatal infants) from climate-policy scenarios (15% below 1990 levels by 2010 for A1 countries and 10% below BAU levels by 2010 for NA1 countries)**

necessarily has several assumptions and includes many uncertainties. Of the many limitations of this exercise, two stand out: we have only calculated mortality impacts of PM for adults over age 30 and infants of age 1 month to 1 year; and we do not provide estimates of morbidities related to air pollutants from fossil-fuel combustion. The quantitative estimates of public-health impacts generated through this assessment should be understood as a first approximation of the likely magnitude of the effect, and not as representing precise predictions of avoided mortalities.

With these caveats in mind, if the climate-policy scenario were to be implemented, substantial improvements in fuel efficiency would be realised by 2020, and major reductions in PM pollution would be achieved. By the end of the second decade of the next century, the policy we have outlined here would avoid about 700 000 deaths annually (90% CI 385 000–1 034 000), of which 563 000 (309 000–831 000) and 138 000 (76 000–203 000) would occur in non-annex 1 (developing) and annex 1 (developed) countries, respectively (table 2). Note that the CI only reflects uncertainties in the epidemiological studies. If BAU climate policies continue, the greatest impacts will occur in developing countries.

We estimate that implementation of the climate-policy scenario could prevent up to 8 million deaths (90% CI 4·4–11·9 million) worldwide during the first 20 years of the next century, corresponding to 1·67 million (0·9–2·5 million) and 6·34 million (3·5–9·4 million) avoided deaths in developed and developing countries, respectively. There are higher expected deaths in developing countries compared with developed countries because of the higher proportional expected changes in PM concentrations under the climate-policy scenario.

To assess the sensitivity of the numbers to certain key assumptions in the estimation of PM concentrations, we considered two analyses. The first assesses the effect of assuming that the USA climate is representative of that in each of the other global regions examined. The second assesses the effects of assuming that there is no change in emission-control levels in the BAU baseline for the non-annex 1 countries and in Eastern Europe and the former Soviet Union. Table 3 presents the results for the cumulative number of deaths avoided under each of these scenarios. If we assume that the climate in the USA is the same in the rest of the world, this results in fewer estimated avoidable deaths than our primary health analysis between 2000 and 2020 in both non-annex 1 countries (3·8 million vs 6·3 million in our primary analysis) and annex 1 countries (1·2 million vs 1·7 million). The alternative assumption, about control levels in the BAU baseline, results in more estimated avoidable deaths in non-annex 1 countries (7·6 million vs 6·3 million).

| Changes in model assumptions | NA1 countries | A1 countries | Total |
|---|---|---|---|
| Primary health analyses | 6 300 000 | 1 700 000 | 8 000 000 |
| Holding worldwide climate estimates same as in the USA | 3 800 000 | 1 200 000 | 5 000 000 |
| Holding emission control levels constant in the BAU in NA 1 and Eastern Europe | 7 600 000 | 1 700 000 | 9 300 000 |

NA 1=developing (non-annex 1) countries; A1=developed (annex 1) countries; BAU=business-as-usual scenario.

**Table 3: Sensitivity analysis of avoidable deaths from climate policy: 2000 to 2020**

## Discussion

One of the most critical set of assumptions in this scenario assessment is that present levels of PM are causing adverse effects on mortality of the magnitude reported by Pope and colleagues. The assumption that fine particles are the direct cause of these effects, and not merely correlated with them is also critical to our analysis. It is these fine particles that can be transported globally because they are not trapped by conventional particulate-control technologies, are buoyant, and can travel thousands of miles through the air before they are deposited. Fine PM can produce effects on health in distant countries.

The climate-policy scenario that we use makes several assumptions that affect the estimates of the public-health impact of improved policies for climate control. We assume an ambitious phase-in of pollution-control equipment in developing countries from policies unrelated to the climate-change-mitigation scenarios. If countries fail to use such pollution-control equipment, air-pollutant emissions will increase, and associated deaths and illnesses will be higher than those estimated under the BAU scenario, as seen in the sensitivity analysis. The effectiveness of policies to reduce greenhouse gas in the climate policy scenario would be even greater. Second, the air-quality modelling protocol we use assumes that the USA distribution of chimney heights is representative of that throughout the world. Many developing countries have lower chimneys for power plants and industrial boilers and greater population densities surrounding industrial facilities, so this assumption probably causes an underestimation of avoided deaths from greenhouse-gas reduction in the non-annex 1 countries. However, if populations are concentrated at greater distance downwind, then lower chimney heights would probably yield lower PM exposures and result in an overestimation of avoided deaths. Third, the analysis does not include reductions in morbidity due to lower PM, or reductions in morbidity from other pollutants.

Baseline reductions

There are several uncertainties associated with the use of the prospective cohort studies for estimation of mortality effects from PM exposure worldwide. While the prospective cohort studies have attempted to account for all important confounders, some potential confounders may not have been considered. However, sensitivity analyses done in the study by Pope and colleagues found that the association between PM and mortality was relatively insensitive to several important potential confounders, including occupational exposure and smoking. This analysis also assumes there is a consistently increasing association between long-term exposure to PM and increased mortality risks, which is the same in the rest of the world as it is in the USA. In most developing countries, exposure to PM is an order of magnitude or more higher than that in the USA. Additional increases in mortality risks could diminish as exposures approach a saturation level. If the exposure response is not the same at these higher doses, then extrapolation of the USA estimates to developing countries may overestimate the avoided deaths in non-annex 1 countries. The results from the Pope study, of adult mortality, probably reflect both the effects of long-term and short-term exposure to PM, and there is possibly some overestimation of the annual avoided mortality associated with estimated annual decrements in PM. Another factor that could lead to overestimation is that PM levels in the USA have generally improved over the past few decades, especially for coarse particulate levels. If the premature mortality effects are related to cumulative exposure over a long period, then the observed effects in the Pope study could be associated with a larger PM change than observed (leading to a smaller risk per unit change).

age dist

Our analysis accounts for the age-distribution of the populations affected. If the RR is higher for older people, then the analysis could overestimate mortality effects in non-annex 1 countries. However, the younger populations of developing countries must often confront other health threatening conditions (eg, malnutrition), which may increase their vulnerability to pollutants. Estimates of the percentage of cardiorespiratory deaths in non-annex 1 countries (except for subSaharan Africa) is similar to that in annex 1 countries, indicating that it is reasonable to apply PM associations found in the USA to other countries. While we are not aware of any attempt to replicate the study by Woodruff and colleagues, similar results of infant mortality associated with PM have been found in the Czech Republic.[40]

est. outdoor PM only

The quantification of mortality benefits derived from our analysis only considers outdoor sources of PM from fossil-fuel combustion. For many countries around the world, burning biomass indoors can also be an important source of PM. For example, in China, households burn about 500 million tons of biomass fuels for cooking and heating each year.[41] The suspended PM in Chinese households often exceeds recommended air-quality guidelines by WHO by more than tenfold.[42] For most of the Chinese population, the health impacts from indoor exposure to air pollutants greatly exceed that of workplace or outdoor exposure. Data from a series of studies and official disease statistics suggest that air pollution from both indoors and outdoors is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide.[43]

In 1990, lower-respiratory-infections were the leading components of disability adjusted life years.[..] By 2020, respiratory-related diseases are projected to rank among the top ten causes of poor health in the world. The total number of annual deaths that could be avoided under the climate-policy scenario in 2020 in much of the developed world almost equals the projected number of fatal injuries caused by automobile accidents.[45] In the USA, by the year 2020, at least 33 000 deaths a year could be avoided from implementation of the climate-policy scenario. This projected number of avoidable deaths in the USA is of the same order of magnitude as currently occurs as a result of several major causes of death from illnesses, each of which is subject to major public-policy interventions, including human immunodeficiency and chronic liver disease.

Newspaper reports this year from Sumatra, Borneo, and other regions[47] indicate that measured levels of air pollution associated both with burning forests and air pollution from energy production sometimes exceed the levels measured in London during the killer fog of 1952. This episode of elevated pollution in London was associated with nearly 3000 excess deaths in 1 week.[48]

Health patterns in any region reflect an intricate combination of factors: poverty, nutrition, population density, housing and sanitation, smoking, and workplace and environmental factors. While environmental factors cannot account for all these patterns, they are important because they can be changed by public policy. Patterns of rapid growth and development in emerging mega-cities of the developing world can impose significant involuntary risks from air pollution on large proportions of their population.[..] Control or prevention of this exposure needs to be recognised as critical to the development of environmental and public-health policy. Even if environmental factors pose relatively small risks of common ailments, but the exposure is widespread and vulnerable groups exist in the exposed population, the public-health impact of air pollution can be significant. Where exposure is universal and where the population is vulnerable the marginal contribution of air pollution can be significant.[..]

### Conclusion

Regardless of how or when greenhouse gases alter climate,[..] reducing them now will save lives worldwide by lessening particulate air pollution. The beneficial effects of reduced particulate pollution appear to be far greater in rapidly developing countries than in developed countries, although they are substantial in both regions. The overall scientific challenge is to discern enough from present and past trends to reduce uncertainties, so that an integrated impact assessment can yield useful results. Our analysis should not be misconstrued as precise predictions, but as relative indicators of the magnitude of the effects that are likely to arise under conditions that we have specified in these climate-related scenarios.

The transdisciplinary activity pursued in this assessment provides a systematic framework for the estimation of potentially far-ranging and substantial health impacts in an uncertain future world. This estimate looks beyond the restricted view of environmental health as a local problem,[..] recognising the truly global reach of climate policies. There is a dynamic between being able to predict future impacts and being able to affect policies to avoid those potential impacts. In the 18th century, the philosopher Saint-Simon noted "savoir pour prevoir" and "prevoir pour pouvoir". With knowledge comes the ability to predict. With the ability to predict, comes the power to change those predictions.

### Contributors

Devra Lee Davis, World Resources Institute (WRI), Tord Kjellstrom and Rudi Slooff, World Health Organization; and Albert McGartland, Environmental Protection Agency (EPA) organised this study. Analyses were provided by Dwight Atkinson, Wiley Barbour, William Hohenstein, Peter Nagelhout, and Tracey Woodruff, EPA; Frank Divita and Jim Wilson, Pechan Associates, Leland Deck, Abt Associates, and Joel Schwartz, Harvard University School of Public Health. All contributed to the writing of this report.

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# Ancillary environmental benefits of cap and trade for developing countries

The reduction of greenhouse gas emissions achieved by developing countries under a cap and trade system will simultaneously reduce the concentrations of numerous other hazardous emissions, producing ancillary environmental and human health benefits. The environmental and health benefits to those developing counties are unlikely to be offset by decreases in environmental quality in the United States because of our strict health-based air quality standards. Thus, in accepting growth targets and emissions trading, developing countries gain not only economically but environmentally -- even with caps at BAU.

As cited in Katie McGinty's post-Kyoto testimony, a recent study in the journal *Lancet* by Devra Lee Davis examines one pollutant that is reduced along with carbon emissions: airborne particulate matter (PM). The study projects that by 2020, a climate change policy scenario in which developing countries reduce emissions to 10% below their BAU and developed countries reduce emissions to 15% below their 1990 levels could produce an annual reduction of 700,000 deaths due to PM exposures. Non-Annex I countries experience 563,000 of those avoided deaths. Over the first 20 years of the study's scenario of climate change mitigation, deaths avoided in developing countries total over 6.3 million.

The analysis below adapts the estimations in the *Lancet* study to estimate the deaths avoided generated by participation of three key developing countries (China, India, and Mexico) in a cap and trade system. The calculations take as given the reductions from BAU that developing countries experience as predicted by the SGM model.

| Trading country | Predicted % Carbon Reduction from BAU | Share of non-Annex I Pop in 2010 | Annual deaths avoided 2010 | Share of non-Annex I pop 2020 | Annual deaths avoided 2020 | Cumulative deaths avoided by 2020 |
|---|---|---|---|---|---|---|
| China | 20% | 23.7% | 136,700 | 22.2% | 250,500 | 2,820,000 |
| India | 18% | 20.3% | 105,300 | 19.8% | 201,000 | 2,264,000 |
| Mexico | 19% | 2% | 19,700 | 2% | 20,900 | 235,000 |

<u>Caveats</u>

The *Lancet* study required heroic assumptions too numerous to mention to derive from LDC targets of 10% below BAU, the resulting fuel use changes, PM and other emissions reductions, PM concentration changes, reduced exposures, and finally, avoided deaths. The analysis above makes several more heroic assumptions:

- Deaths avoided in each non-Annex I country are proportional to the country's share of non-Annex I population. For example, since China is about 24% of the non-Annex I population in 2010, we assume China will experience 24% of the deaths avoided.

- Emissions reductions below 10% of BAU result in the same incremental avoidance of deaths. For example, we assume that a 20% departure from BAU has double the effect of a 10% departure.

- The mortality decreases for developing countries that derived from their departure from BAU do not depend on the targets attained by developed countries. The *Lancet* model assumed that Annex I countries would achieve targets 15% below 1990 emissions levels rather than the targets in the Protocol. Here we assume that difference does not affect the developing country mortality reductions.

- The timing of emissions reductions is consistent with the timing of reductions modeled in the Lancet article. This timing probably differs from timing predicted by SGM.

## Annex B

| | Party | Quantified emission limitation or reduction commitment (percentage of base year or period) |
|---|---|---|
| | Australia | 108 |
| | Austria | 92 |
| | Belgium | 92 |
| | Bulgaria* | 92 |
| | Canada | 94 |
| | Croatia* | 95 |
| | Czech Republic* | 92 |
| | Denmark | 92 |
| | Estonia* | 92 |
| | European Community | 92 |
| | Finland | 92 |
| | France | 92 |
| | Germany | 92 |
| | Greece | 92 |
| | Hungary* | 94 |
| | Iceland | 110 |
| | Ireland | 92 |
| | Italy | 92 |
| | Japan | 94 |
| | Latvia* | 92 |
| missing from dataset | Liechtenstein | 92 |
| | Lithuania* | 92 |
| | Luxembourg | 92 |
| missing | Monaco | 92 |
| (includes Ant + Aruba) | Netherlands | 92 |
| | New Zealand | 100 |
| | Norway | 101 |
| | Poland* | 94 |
| | Portugal | 92 |
| | Romania* | 92 |
| | Russian Federation* | 100 |
| | Slovakia* | 92 |
| | Slovenia* | 92 |
| | Spain | 92 |
| | Sweden | 92 |
| | Switzerland | 92 |
| | Ukraine* | 100 |
| includes | United Kingdom of Great Britain and Northern Ireland | 92 |
| (Puerto Rico) | United States of America | 93 |

* Countries that are undergoing the process of transition to a market economy.

Parr. James

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(703) 425-7729

| Country | Pop in 2010 | Pop in 2020 | (pop) Share of non-Annex B in 2010 | (pop) share of non-Annex B 2020 |
|---|---|---|---|---|
| China | | | .x y | |
| India | | | | |
| Mexico | | | | |
| Korea | | | | |
| Brazil | | | | |
| | | | x. | y. |

Zach

Please make a spreadsheet table like this

non-Annex B is all countries not on the attached list.

Thanks!

Adele 5-5012

(save your work ---.
we may add more countries to the list)

| Country | Pop in 2010 | Pop in 2020 | Share of non-Annex E in 2010 | Share of non-Annex E in 2020 |
|---|---|---|---|---|
| China | 1,388,474 | 1,488,075 | 23.7% | 22.2% |
| India | 1,189,082 | 1,327,110 | 20.3% | 19.8% |
| Mexico | 117,651 | 130,645 | 2.0% | 2.0% |
| Korea | 50,764 | 53,293 | 0.9% | 0.8% |
| Brazil | 199,327 | 220,567 | 3.4% | 3.3% |

Hi Adele!

I e-mailed the spreadsheet as well. Let me know if you need anything else.

- Don

PS. See penciled-in notes on stapled cover sheet for missing countries.

# Proposal for Developing Countries: To Cap and Trade Carbon Emissions Permits

**I. The best form of participation by developing countries in the Kyoto Protocol would be a) acceptance of binding caps slightly below business as usual and b) agreement to trade emission permits internationally. Therefore such participation should be our top priority in international negotiations.**

A. The economic rationale for such participation includes

- **Greater cost savings to the U.S.:** Participation by developing countries in international permit markets would greatly lower the costs to the U.S. of meeting the Kyoto cap (as CEA testimony showed). In particular, costs would be lower than with trading among only Annex I countries, and even lower than with such trading and the intrinsically less efficient project-by-project approach of CDM.

- **Greater environmental benefits:** Caps slightly below business as usual would lower global emissions, and provide environmental benefits not achievable by pursuing CDM, which only redistributes emissions geographically.

- **Greater economic benefits to developing countries:** With targets slightly below BAU, developing countries would enjoy net gains of many billions of dollars through the international sale of emission reductions achieved at lower cost than the world price. Moreover, an emissions permit market would yield greater gains than are available through CDM.

B. Non economic rationales include the long-run benefits of including developing countries into global negotiations, and greater compliance with the Byrd-Hagel resolution.

**II. Problem:** To persuade a developing country *voluntarily* to adopt a cap and then to trade permits internationally, international agreements must be structured to reduce the risk of inadvertent stringency and in particular to reduce the possibility of a cap so stringent as to cause economic losses to the developing country.

**Proposed Solution: Negotiations should focus on slight reductions from the business as usual emissions level, where this level is expressed in a way that depends on the *future* values of economic variables.**

Rationale: Such caps would avoid the risk of inadvertent stringency associated with higher than projected economic growth between now and the beginning of the commitment period in 2008. Developing countries would face only the much smaller risk that emissions would be higher than expected *given* the economic conditions realized in 2007.

Basic principles for implementing such an approach are:

- **Reasonable Forecasts**: The relationship between the cap (ignoring any real reductions in emissions) and the values of economic variables, when applied to emissions and such variables during recent years, should predict emissions reasonably well (and be without demonstrable statistical bias). Relationships that give reasonably precise predictions reduce the risk of both inadvertent stringency and paper tons which could increase global emissions.

- **Predetermined Caps:** The cap should not depend on contemporaneous values of economic variables, so as to avoid uncertainty during the commitment period about the country's cap. For example, the cap should not vary with 2008 or 2010 GDP levels, although it may vary with 2007 GDP.

- **No Perverse Incentives:** The cap should depend on values of economic variables only indirectly related to emissions, to avoid creating perverse incentives for developing countries to increase emissions so as to have higher caps in the commitment periods. For example, the cap should not depend on energy consumption in 2007.

**Illustration:** One sensible way of implementing the solution is described below. Other ways of implementing the solution may work as well or better. The conclusions are stated below and the details of our work follows

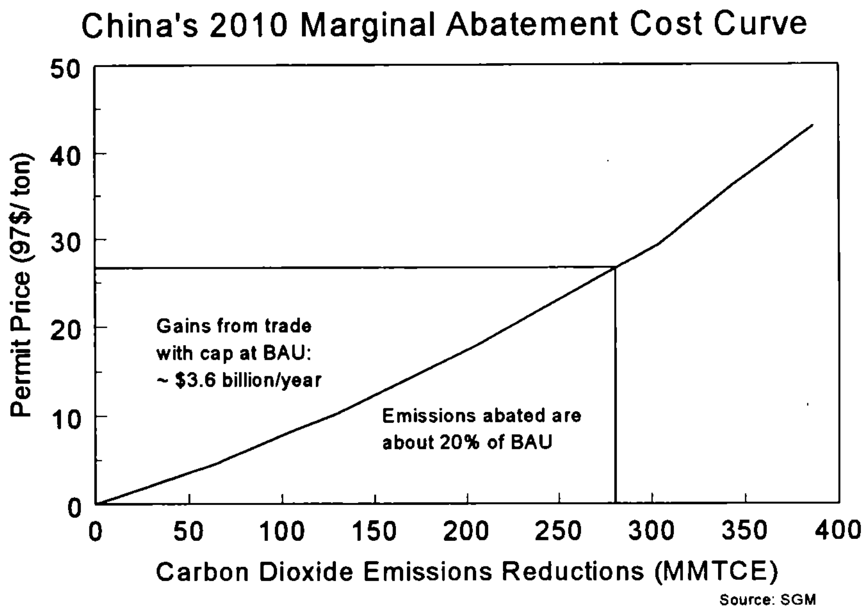
- Defining the business as usual level for a developing country as a function of its lagged GDP and lagged population and setting the emissions cap at that level yields a negligible risk of leaving the developing country worse off under cap and trade because of inadvertent stringency. A cap slightly below BAU would also yield negligible risk of leaving the developing country worse off.

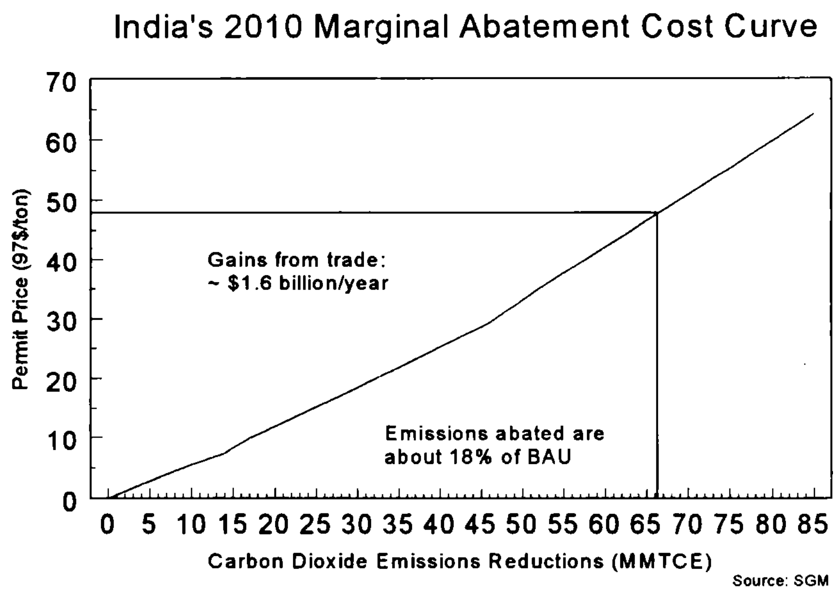
- Emissions caps for developing countries set below their business as usual emission level will result in lower gains from trade but provide environmental benefits. The higher costs of a cap set below BAU are borne by both the developing countries and the Annex I countries.

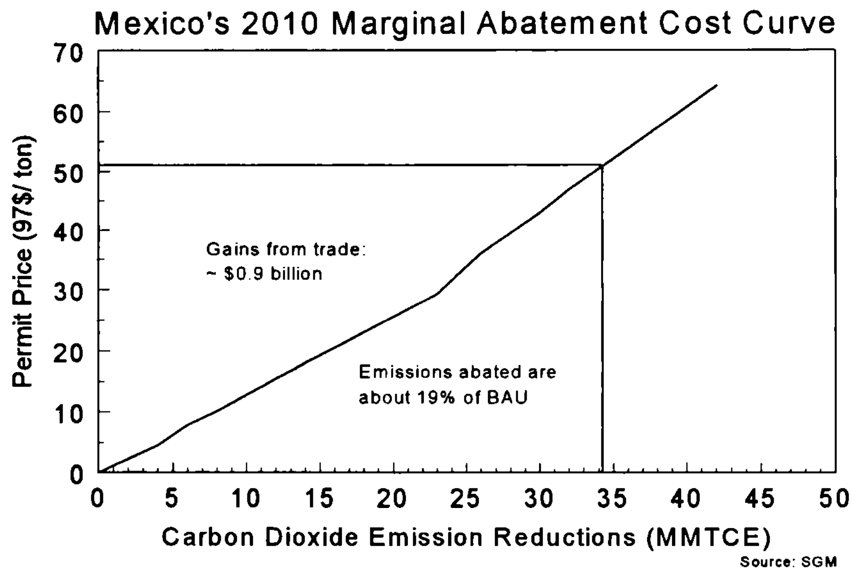
There are significant gains from trade for large developing countries and large cost-savings to the U.S. if just one developing country accepts an emissions cap at BAU and participates in emissions trading. The following table illustrates these gains from trade from a baseline of full Annex I trading.

| Trading Scenario | Country | Permit Price (97$/ton) | Gains from Trade |
|---|---|---|---|
| Annex I only | United States | $54 | not applicable |
| Annex I + China | China | $26 | $3.6 billion/year |
| Annex I + China | United States | | $11.6 billion/year[1] |
| Annex I + India | India | $47 | $1.6 billion/year |
| Annex I + Mexico | Mexico | $51 | $0.9 billion/year |

[1] Gains from trade for the U.S. are estimated based on the reduction in cost to the US of trading in Annex I plus China.


China's 2010 Marginal Abatement Cost Curve
Permit Price (97$/ ton)
0
10
20
30
40
50
0
50
100
150
200
250
300
350
400
Carbon Dioxide Emissions Reductions (MMTCE)
Gains from trade
with cap at BAU:
~ $3.6 billion/year
Emissions abated are
about 20% of BAU
Source: SGM


India's 2010 Marginal Abatement Cost Curve
Permit Price (97$/ton)
0
10
20
30
40
50
60
70
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Carbon Dioxide Emissions Reductions (MMTCE)
Gains from trade:
~ $1.6 billion/year
Emissions abated are
about 18% of BAU
Source: SGM


Mexico's 2010 Marginal Abatement Cost Curve
Permit Price (97$/ ton)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
Gains from trade:
~ $0.9 billion
Emissions abated are
about 19% of BAU
Carbon Dioxide Emission Reductions (MMTCE)
Source: SGM

Summary of Analysis:

A. Data

We have compiled data on 3 variables: emissions of carbon dioxide, GDP, and population for 117 countries for the time period 1970-1992. The carbon dioxide emissions data, measured in millions of metric tons of carbon, are from the Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory, DOE). The GDP data, measured in 1987 U.S. dollars, are from the World Bank. The population data, measured in thousands of individuals, are from the United Nations Population Division.

B. Methods

We have estimated a fixed effects linear regression on the logs of these variables, for the countries in our data set, excluding those listed in Annex I. Our regression uses four non-overlapping 5 year intervals for each country. The residuals exhibit slight serial correlation (estimated first order serial correlation $\approx .15$). Our forecasts include the country specific constants.

C. Results

The fixed effects regression we estimated is

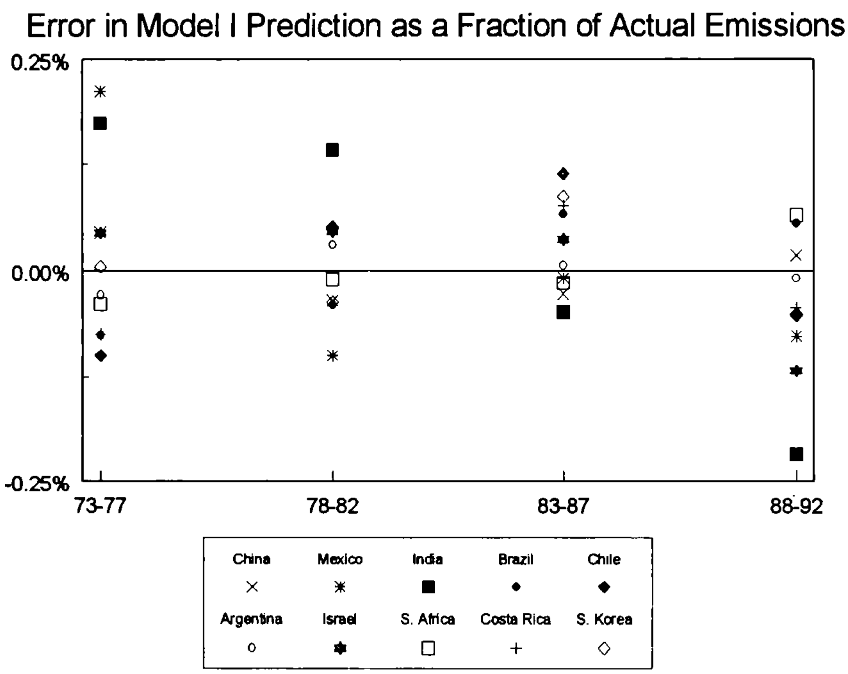
$$\text{Emissions} = a\ \text{GDP}_{t-1} + b\ \text{GDP}_{t-2} + c\ \text{Population}_{t-1} + \gamma\ \text{trend}$$

Emissions are the natural logarithm of the five year non-overlapping average of carbon emissions. All independent variables are lagged. $\text{GDP}_{t-1}$ is the log of the gross domestic product in the year prior to the first year in the emissions variable, $\text{GDP}_{t-2}$ is GDP in the year two years prior to the first year included in the emissions variable, and $\text{population}_{t-1}$ is the country's population in the year prior to first year included in the emissions variable. Trend is one in the first 5 year period, and 2, 3 and 4 respectively in the subsequent 5 year periods. The useable data included 376 cross-section time series observations. The fixed effects regression used 98 degrees of freedom. The R squared was in excess of 0.99.

Model I Results

| Variable Name | Coefficient Estimate | Standard Error |
|---|---|---|
| $GDP_{t-1}$ | 0.9501823 | 0.2443047 |
| $GDP_{t-2}$ | -0.411297 | 0.23894 |
| $Population_{t-1}$ | 0.4836006 | 0.2055439 |
| trend | 0.0073712 | 0.0310638 |

As one illustration of the model's accuracy in predicting emissions, consider the chart below that maps actual and predicted emissions using within sample data for ten selected developing countries. The predicted value is never more than 1/4 of one percent away from the actual emissions average for any of the five year intervals.



To forecast emissions for the five year period beginning in 2008 using the results of this regression we input the World Bank forecasts of GDP for the years 2007 and 2006, and the United Nations forecasts of 2007 population. The forecasts of emissions for the budget period and the confidence intervals around these forecasts conditional on the assumed 2006 and 2007 values are described in the table below.

| Country | 2006 GDP (1987$, billions) | 2007 GDP (1987$, billions) | 2007 Population | Predicted Average Emissions, 2008-2012 |
|---|---|---|---|---|
| China | 1,385.8 | 1,493.5 | 1,357,627,000 | 2092 MMTC SE: 1.37 MMTC |
| India | 752.1 | 799.7 | 1,140,563,000 | 345 MMTC SE: 1.34 MMTC |
| Mexico | 268.2 | 282.7 | 113,385,000 | 157 MMTC SE: 1.33 MMTC |

The 95 percent confidence interval around the predicted emissions is approximately ± two standard errors. As shown above, these developing countries would incur net costs of a cap and trade only if the cap were about 9 to 10 percent below BAU. Since such reductions from BAU are more than 10 times greater than the standard error, the risk of net costs is negligible.

## How Far Below BAU Should the Developing Countries' Caps Be Set?

The answer to this question has many dimensions. Most commonly discussed is the issue of fairness: what commitments to reduce emissions should be made by countries whose economic resources differ substantially? Generally neglected but discussed below is the issue of efficiency. In particular, what are the implications for U.S. costs of increasingly more stringent caps on emissions from key developing countries?

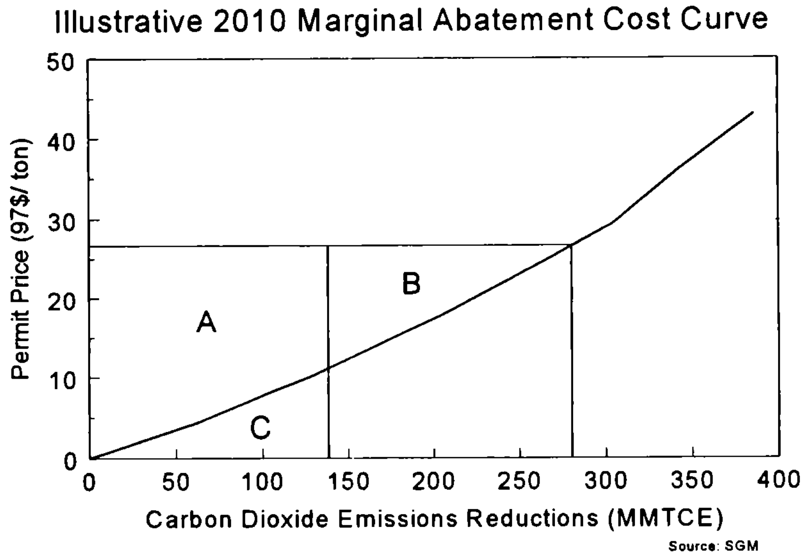
More stringent developing country caps raise U.S. costs by restricting the supply of permits in world markets and so raising the price of permits. To assess the magnitude of this effect consider the cap which just leaves a country no better off than no cap at all. This "indifference" cap is where the costs of meeting the cap just equal the net gains from selling permits in world markets. In the figure on the next page illustrates gains from trade for a small country. For a cap that is equivalent to a reduction from BAU of 138 MMTCE, net foreign exports are B, and the cost of meeting the cap is C. Since B=C in this example, the net gains from trade are nil.

Imposing this "indifference" cap on China, given that its participation does affect world permit prices leads to the following conclusions.

1) An indifference cap for China increases annual U.S. costs by $4.5 billion or 33% relative to a BAU cap for China.

2) The cost to the U.S. per ton of Chinese emissions reduced is $26 on average. (The marginal cost effectiveness is likely to be higher.) This is <u>not</u> the average cost of a ton of emissions purchased from China, but the average cost to the U.S. of China complying with a more stringent cap.

Thus developing country participation in the form of acceptance of caps significantly more stringent than business as usual will raise costs to the U.S.


Illustrative 2010 Marginal Abatement Cost Curve
Permit Price (97$/ton)
50
40
30
20
10
0
A
B
C
0
50
100
150
200
250
300
350
400
Carbon Dioxide Emissions Reductions (MMTCE)
Source: SGM

| Share of non-Annex E in 2010 | Deaths avoided in 2010 | Share of non-Annex E in 2020 | Deaths avoided in 2020 |
|---|---|---|---|
| 0.23723 | 136644 | 0.22243 | 250453 |
| 0.20316 | 105319 | 0.19837 | 201026 |
| 0.02010 | 10999 | 0.01953 | 20889 |
| 0.00867 | 4996 | 0.00797 | 8970 |
| 0.03406 | 19616 | 0.03297 | 37123 |

LEVEL 1 - 2 OF 2 STORIES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HEADLINE: Short-term improvements in public health from global-climate policies on fossil-fuel combustion: an interim report; Working Group on Public Health and Fossil-Fuel Combustion

BODY:

Summary

Background Most public-health assessments of climate-control policies have focused on long-term impacts of global change. Our interdisciplinary working group assesses likely short-term impacts on public health.

Methods We combined models of energy consumption, carbon emissions, and associated atmospheric particulate- matter (PM) concentration under two different forecasts: business-as-usual (BAU); and a hypothetical climate-policy scenario, where developed and developing countries undertake significant reductions in carbon emissions.

Findings We predict that by 2020, 700000 avoidable deaths (90% CI 385000-1034000) will occur annually as a result of additional PM exposure under the BAU forecasts when compared with the climate-policy scenario. From 2000 to 2020, the cumulative impact on public health related to the difference in PM exposure could total 8 million deaths globally (90% CI 44-119 million). In the USA alone, the avoidable number of annual deaths from PM exposure in 2020 (without climate-change-control policy) would equal in magnitude deaths associated with human immunodeficiency diseases or all liver diseases in 1995.

Interpretation The **mortality** estimates are indicative of the magnitude of the likely health benefits of the climate-policy scenario examined and are not precise predictions of avoidable deaths. While characterised by considerable uncertainty, the short-term public-health impacts of reduced PM exposures associated with greenhouse-gas reductions are likely to be substantial even under the most conservative set of assumptions.

Introduction

Since the industrial revolution, the contribution of anthropogenic sources of greenhouse gases to the global environment has increased significantly.1 Atmospheric concentrations of greenhouse gases, including carbon dioxide ($CO_2$), methane (CH4), and nitrous oxide (N2O), are of greater importance today than at any other time in human history. These trends can be largely attributed to human activities, primarily fossil-fuel combustion, and change in land use and agricultural practices. In the absence of efforts to reduce greenhouse gases, the concentrations of these gases are expected to grow sig- nificantly throughout the next century. The mid-range estimate from the Intergovernmental Panel on Climate Change (IPCC) is that human-induced climate-change will increase surface temperatures by about 20C by the year 2100;2 many uncertainties exist about this projection.

In an effort to protect the global-climate system for future generations, over 150 nations signed the UN Framework Convention on Climate Change (UNFCCC) in June, 1992.3 The UNFCCC established the objective of stabilising atmospheric greenhouse-gas concentrations at levels that would avoid dangerous anthropogenic interference with the global-climate system. Signatory countries will be considering options to control greenhouse gases at the third con- ference of parties in Kyoto, Japan, in December, 1997.

Short-term public-health impacts have generally not been considered in assess- ments of global-climate change. Two **studies**,4,5 for example, have projected that well into the next century, weather patterns resulting from climate change are expected to affect the health of future generations. Heat-related **mortalities** and illnesses, physical and psychological traumas, and changes in vector-borne and infectious diseases, food supplies, and coastal sea-levels are expected to become evident. With various models, we estimate likely public-health benefits of current and future global-climate-change mitigation policies in the first two decades of the 21st century in developed and developing countries.

Many of the fossil-fuel combustion processes that produce CO2 and other green- house gases also produce a host of air pollutants such as particulate matter (PM), sulphate, ozone, and other pollutants, all of which have short-term adverse effects on public health. We use PM as a sentinel air pollutant because it is commonly associated with fossil-fuel combustion. Extensive public-health literature in several countries has shown that both **mortality** and morbidity are significantly associated with exposure to PM.6,7 Most air pollutants from fossil fuels have local impacts but some **airborne** pollutants (eg, fine particulates) can be transported thousands of miles and have global impacts.8

We combined analyses from several independent models of energy consumption (to provide a first approximation of likely CO2 emissions), associated concentra- tions of PM, and probable increases in **mortality** associated solely with PM by the year 2020 (figure 1). This analysis presents a scenario-based order-of-magnitude estimate of the possible size of the air-pollution impacts on populations in developed and developing countries.

Methods

Scenario development

Estimation of the consequences for public health of projected global events requires the development of scenario-based impact assessment that relies on complex models of environmental change.9 Our **study** develops two possible CO2 emission scenarios: a business-as-usual (BAU) scenario which updates IPCC's 1992 analysis of expected trends in energy consumption and associated CO2 emissions;10 and a hypothetical climate-policy scenario, which considers the stated intentions of the European Union regarding proposed reductions in CO2 emissions for developed countries,11 coupled with additional measures by developing countries. Under our hypothesised climate-policy scenario, developed countries would undertake concerted and binding efforts to reduce energy-related CO2 emissions 15% below 1990 levels by the year 2010. Under this same climate-policy scenario, developing countries are assumed to reduce their emissions 10% below their levels of greenhouse-gas emissions forecast for 2010--that is, 10% below what would otherwise be their BAU trends by 2010. This is consistent with agreements made by developing countries under the Ber- lin Mandate to advance implementation of existing commitments to promote tech- nologies, practices, and processes that reduce greenhouse-gas emissions.

Both these scenarios assume that total energy use and efficiencies in the developing countries continue to increase to meet the needs of economic growth. The differences between them lie in the rates of growth in energy use, the fuel mixes, and their combustion and end-use efficiencies. Under each of these scenarios, emissions of PM are taken as representative of general ambient air pollution associated with fossil-fuel combustion and CO2 emis- sions. Based on projected concentrations of PM, we estimate annual and cumula- tive numbers of avoidable deaths in the years 2010 and 2020 among adults aged over 30 years and infants of up to 1 year in developed (annex 1) and develop- ing (non-annex 1) countries (UNFCCC nomenclature). Avoidable deaths refers to the estimated annual premature **mortality** associated with PM from modelled fos- sil-fuel combustion (ie, attributable risk) that could be avoided by adopting the hypothesised climate-policy scenario. Because the aerodynamic size of the particles produced is of great importance, our model estimates the emissions and concentrations of particles that are less than 10 m (PM10) and fine particles of less than 25 m (PM25). A host of other adverse acute and chronic health effects are also associated with PM and other air pollutants, but are not analysed here.12,13

Fossil-fuel consumption and carbon emissions

Future fossil-fuel consumption and resulting emissions of greenhouse gases and other air pollutants reflect complex interactions of several key variables, including economic activity, transportation modes, demographic trends, the rate and nature of technological innovations, and energy prices. The IPCC devised six well-documented projections of greenhouse-gas emissions in 1992.14 The IPCC used the Atmospheric Stabilisation Framework (ASF) model to relate socioeconomic scenarios to carbon emission trajectories. The ASF model con- tains detailed representations of fossil-fuel consumption for four sectors (electric utility, residential/commercial, industrial, and transportation) for nine global regions.

All CO2 emission estimates in this paper refer to emissions attributable to the combustion of fossil fuels, which represent about 75% of current global anthropo-genic emissions of CO2.15 The CO2 emission projections presented in this paper fall within the range of other emission projections documented in the literature. The 83 billion metric tonnes of carbon (BMTC) from fossil-fuel combustion presented in this paper for 2010 is slightly lower than the estimate of 88 BMTC as predicted by Energy Information Administration.16 Our 2020 projection of 107 BMTC is higher than the IIASA/WEC projection of 84 BMTC17 and similar to the Shell Oil sustained-growth scenario estimate of 105 BMTC.18

The input in this **study** has been updated to reflect more recent population projections, the breakup of former Soviet Union, and lower anticipated fossil-fuel prices. The model assesses CO2 emission-reduction goals, by choosing the most efficient and least cost emission- reduction opportunities available in each region, and recognises efficiency improvements in many developing countries.19 The global-population data used for these scenarios are consistent with the World Bank's medium-growth assumptions.20 The gross national product (GNP) growth assumed for the BAU scenario is slightly higher than the one used in the IS92a scenario, which reflects several economic, energy, and climate-change-related **studies**.21,22

Table 1 and figure 2 indicate several trends and associations of fossil-fuel consumption patterns modelled under both the BAU and climate-policy scenarios. In 1990, despite having only 24% of the world's population, annex 1 countries accounted for 70% of global fossil-energy consumption and 68% of carbon emissions from fossil fuels. Under BAU, overall growth in CO2 emissions from annex 1 countries is relatively moderate through the projection period, 1990-2020, rising by only 175% through 2020. This moderate growth may be explained by current trends of fossil-fuel consumption patterns in Russia and the former Soviet Union. These regions markedly differ from other annex 1 countries, in that sharp declines in energy consumption are not assumed to reach 1990 levels again before 2020. As a consequence, future increases in emissions in annex 1 countries under the BAU scenario are masked by these reduced consumption patterns in Russia and the countries of the former Soviet Union.

The expected growth in energy-related CO2 emissions of non-annex 1 countries under BAU by 2020 exceeds the total level of emissions of annex 1 countries in 1990. Non-annex 1 countries' carbon emissions resulting from consumption of fossil fuels are expected to rise from 19 BMTC in 1990 to 41 BMTC in 2010, a 116% increase over 30 years. In 1990, annex 1 countries produced 68% and non-annex 1 countries produced only 32% of total global carbon emissions. Under the BAU scenario, by the years 2010 and 2020, non-annex 1 region's projected contributions will be 41 and 6 BMTC, respectively. On the other hand, if the climate-policy scenario is implemented, by the years 2010 and 2020, non-annex 1 region's projected carbon emissions could be reduced to 37 and 54 BMTC, respectively. Figure 2 shows the relative contributions of developed and developing countries to fossil-fuel use for the years 1990, 2010, and 2020 under both scenarios. The global fossil-fuel consumption is expected to be less under the climate policy scenario, which reflects increased fuel-combustion efficiencies, conservation measures, and improved technologies. We assume that there is no cross-border trading of greenhouse gases. Under the climate-policy scenario, CO2 emissions decrease more than fossil-fuel consumption as countries switch away from coal to less polluting fuels, such as natural gas.

Pollutant emissions and concentrations

The following discussion outlines the modelling protocol followed in this **study** along with a brief description of key assumptions and sensitivity analyses.

A PM source-receptor matrix23 was used to derive concentration patterns for PM10 and PM25 per unit of energy use for each of the four sectors and three fossil-fuel types (coal, oil, and natural gas). The source-receptor coefficients were calculated with large-scale air-dispersion models that were based on emission inventories calibrated with and matched to extensive monitoring data in USA for 1990-1994.24 In addition to calculation of concentrations of primary particles (those emitted directly by sources), the model also incorporates the secondary conversion of gaseous precursors (SO2 and NOx) to fine particulates as they are transported through the lower atmosphere. The source-receptor-matrix model yields smoothed, area-wide averages of PM10 and PM25 concentrations for each IPCC region and does not estimate local air- borne-pollutant levels at specific receptor sites; the latter air-pollutant estimates are generally calculated with Gaussian air-dispersion models that incorporate only local emission inventories and meteorological data. To do this analysis, we assume that **airborne** fine particles travel hundreds of miles through the atmosphere and their estimated regional concentrations are not very sensitive to the details of the modelling matrix. This contrasts with the well-known difficulty of modelling for short-term ozone episodes over a small geographic area. Evidence supporting the long-range transport of fine particles can also be found--eg, in the report of the second World Meteorological Organization meeting of experts to assess the response to and atmospheric effects of the Kuwait oil fires.25

Applying such a large-scale air-dispersion model carries with it several assumptions that could result in a misestimation of actual PM concentrations. In the absence of data on typical chimney heights in other parts of the world, for example, we have assumed that the distribution of chimney heights in the USA is representative of that found elsewhere. Should average heights of chim- neys in a given region be lower than in the USA, the likely consequence would be higher local concentrations of particles and their precursors, and lower concentrations at greater distances downwind. Conversely, higher chimneys could yield lower concentrations near a given source but higher concentrations further downwind. A second key assumption is that the spatial association between emission sources and population densities in the USA is representative of the rest of the world. In some developing regions, such as the mega-cities of Southeast Asia, whose population patterns are more geographically dense, this approach is likely to underestimate actual human exposures to **airborne** pollutants. Also, the source-receptor-matrix model makes no estimates of indoor air-pollutant exposures to PM from coal or biomass used for cooking and heating. Such exposures are known to be very high in several developing regions, such as China, Africa, and India.26

Our modelling indicates that concentrations of PM from a fixed quantity of emissions in hot and dry regions are about one-third of what would be expected from those same emissions under most other climatic conditions. The likely reasons for this are: higher ambient temperatures coincide with greater mixing heights, hence a greater volume of air for dispersion; and the conversion of gaseous PM precursors such as SO2 into intermediate products (sulphuric acid) requires the presence of water vapour. Where less water vapour is available, conversion rates are slower and conversion takes place over longer distances. Therefore, regional levels of PM are expected to be lower in dryer climates.

To capture these influences of climate on PM concentrations, the USA was divided into four roughly equal geographic zones based on long-term climatic data: hot/dry, hot/wet, cold/dry, and cold/wet. Unique source strengths for each sector/fuel were derived for each zone. Similar climatic data for each of the remaining eight global regions were used along with data on population densities to obtain the appropriate, representative weighting among USA climate zones--eg, 90% of the population of the Southeast Asia group was found to reside in a


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climate which most closely resembles the hot/wet designation, while 10% resides in a hot/dry grouping; none was in the cold/dry or cold/wet zones. To derive an overall Southeast Asia estimate, the source-receptor association for the hot/wet USA zone was weighted 90%, and the hot/dry zone 10%. Had we not adjusted the source-receptor matrix to account for regional differences for climate, and instead used the USA climate as a proxy for the rest of the world, then the modelled concentrations of PM would have been from 16% (climate policy Asia) to 130% (climate policy Europe) lower.

This analysis projected future global patterns of energy consumption and adjusted the overall USA source-receptor association to account for climate differences in other global regions. To project likely changes in concentrations of PM, it is also necessary to estimate future efficiencies of pollution-control equipment and policies unrelated to climate-control mitigation. In our analysis, two alternative pollution-control strategies were assumed to occur, in developed and developing regions. The USA Organisation for Economic Co-operation and Development (OECD)-West and OECD-Asian countries were assumed to use USA controls, including SO2 and NOx controls outlined in the USA, 1990, Clean Air Act. These do not reflect controls that individual states of the USA might adopt as a result of recent revisions to ozone and PM National Ambient Air Quality Standards, which are not expected to go into effect until after the adoption of climate-change mitigation strategies. All other regions were assumed to start with no controls in the year 2000. By the year 2020, these other regions were assumed to attain 1990 USA control levels for transportation-related emissions and 1970 USA control levels for point-source emissions.

Our results are sensitive to the estimation of pollution-control efficiencies for fuel combustion because emission rates change in relation to these values. This is especially true for situations where high levels of control are estimated, because the difference between 90% and 99% control is a ten-fold difference in emissions. For countries that may have more stringent control programmes than the USA (eg, certain sectors in Japan), use of USA standards as a proxy may overestimate future PM concentrations. It is also possible that our assumptions about future pollution-control efficiencies are too optimistic for developing countries; if so, then we will have underestimated emissions and associated health effects of the control scenarios. The sensitivity of the analysis to assumed control levels was evaluated by calculating PM concentrations in non-annex 1 regions and Eastern Europe and former Soviet Union, which would result in the absence of controls. Analysis for 2020 showed that removing controls would yield PM10 and PM25 concentrations of 65% and 32% higher, respectively, than the values calculated in the BAU analysis.

Further refinements to transportation-related emissions in all non-USA regions were made to account for the much higher reliance on diesel fuel in most of the world than in the USA.27,28 The fraction of the energy consumed in the transportation sector which is diesel fuel is different in each country (eg, 60% in Latin America, 20% in the USA) and the fraction is assumed to remain constant throughout the **study** period. These refinements also assume a steady reduction in use of lead in petrol starting from present levels in the year 2000 to zero in 2010. Increased use of catalytic converters to control vehicle-exhaust pollutants will accompany phase-out of lead.

In the USA, data indicate that ambient PM10 concentrations are on average 65%

of total suspended particulate concentrations; PM25 concentrations are on an average about 50% of PM10 concentrations; and fossil-fuel combustion accounts for about 45% of measured PM25 concentrations.23,24 To validate modelled PM concentrations, ambient monitoring data were gathered for about 40 countries. Virtually all of the data, however, were for total suspended particulate and no data were found which established the fractional contribution from fos- sil-fuel combustion. If one were to assume that the percentage of total suspended particulate that is contributed by fuel-combustion sources in the USA holds throughout the world, then estimated PM concentrations should be two to ten times higher than those developed in this **study.** In our judgment, it is highly unlikely that other regions experience long-term average PM concentra- tions from fossil-fuel combustion that approach such levels. Total suspended particulate concentrations in most of the world are at least twice as high as those in the USA; this is likely due to factors such as much higher contribu- tion to the coarser fraction (>25 m) from such sources as wind-blown dust (eg, Middle East) as well as a higher fine fraction (<25 m) contribution from sources such as biomass burning from heating, cooking, and forest clearing (eg, Southeast Asia).

Health-impact estimates

Extensive public-health literature in several countries shows that both **mortality** and morbidity are significantly associated with exposure to PM.6,7 Besides **mortality, studies** in several countries have associated PM with car- diovascular and respiratory morbidity (eg, increased hospital admissions and emergency-room visits for acute and chronic pulmonary effects, including bron- chitis, asthma, cough and wheeze).6,7,29 Little is known about the mechanism of action of PM. Some toxicological **studies** have produced bronchitic responses,30 arrhythmias,31 and exacerbation of pneumonia in rats33 from exposure to fine particles, which are similar to those observed in epidemiological **studies.** It has been found that tiny respirable particles or **airborne** aerosols can interfere directly with pulmonary function and plasma viscosity in animals and human beings.33-35 **Mortality** effects have con- sistently been associated with short-term and long-term exposure to PM in more than 40 **studies** done in over ten countries.6,7,36-38

The short-term exposure **studies** use daily time-series analysis to assess changes in **mortality** in the general population that are associated with changes in daily concentrations of PM. Long-term exposure **studies** of PM have used a prospective cohort design, which allows the adjustment of potential confounders in the assessment of the association between PM and **mortality.**

Health benefits from reductions in PM have been derived previously from epidemiological **studies** done in the USA and in Europe.29,38,39 Long-term exposure **studies** were used as the basis for the quantitative analysis because the results from these analyses have followed single cohorts and adjusted for important confounders. These analyses suggested **mortality** effects from both long-term and short-term exposure to PM.6,7,41 Epidemiological **studies** were chosen for this quantitative analysis only if they reported the relative risk (RR) as a monotonic function of PM concentrations. The two age groups for which RR has been estimated in long-term **studies** are adults aged over 30 years and infants aged between 1 month and 1 year. To evaluate the impact of PM con- centrations on adult **mortality,** the paper by Pope and colleagues was selected as the basis for quantitative analysis.42 For infant **mortality,** we used a **study** by


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Woodruff and colleagues43 that reported RR as a continuous monotonic function of PM concentrations. Pope and colleagues found that a 245 g/m3 increase in PM25 is associated with a 117 (95% CI 109-126) increase in RR of total **mortality** for adults over 30 years. Woodruff and colleagues, found that for a 10 g/m3 increase in PM10, an odds ratio of 104 (95% CI 102-107) for increases in total infant **mortality** between 1 month and 1 year associated with increases in PM10 concentrations.

We assume that the association is the same in the rest of the world as it is in the USA. Epidemiological **studies** have found a relatively consistent association between short-term exposures to PM and **mortality** in many countries, including Chile, Brazil, and Western Europe.6,37 Given the relatively consistent association found between short-term exposure to PM and **mortality** across countries, it is reasonable to assume that the health effects from long-term exposures to PM in other regions of the world parallel those of the USA.6 The association between change in PM25 and PM10 and change in **mortality** risk is modelled as an exponential function. The exponential func- tional form for the RR comes from the specification of the logistic regression model used in the **study** by Woodruff and colleagues, and the Cox's proportional hazard model used in the Pope **study** for evaluation of the association between PM and **mortality**. In this model, the RR associated with a PM change of D PM is:

RR (PM) = exp (b D PM)

The slope coefficient, b, is derived from the chronic-exposure epidemiological **studies** selected for use in this analysis, and D PM is the incremental change in the annual mean (or median) PM concentration, had a policy-based scenario not been adopted. The risk reduction associated with adoption of the policy is:

[exp (b D PM)-1].

The estimated regional incidence of avoided premature morality is:

D **mortality**=(RR [D PM]-1) (**mortality** rate) (population), where the **mortality** rate and population are the adult or post-neonatal regional estimates, derived from projections of population by age and infant **mortality** rates by country. These were obtained from the Bureau of Census (USA) international database and aggregated to a regional level. The projected baseline age-adjusted regional adult (>30 years) **mortality** rates were calculated from individual country population projections (by 5-year age group), adjusted for immigration and emigration with World-Bank projected net-migration rates.

The source-receptor-matrix estimates annual mean PM concentrations. The RRs in the Pope **study** are based on the annual median of daily PM concentrations, which is usually lower than the mean for air-pollution concentrations.42 PM data, from the USA, suggests that a g distribution best describes the observed skewed distribution of daily PM levels.39 Assuming a g distribution, an estimated median can be derived from the mean and an estimated maximum daily level. Observed population-weighted peak-to-mean ratios from four USA geographic zones are applied to the source-receptor association. A maximum likelihood routine was used for each region in the climate-policy scenario to estimate the g distribution with the estimated mean and maximum daily level.

Results

The scenarios that form the basis for this exercise rest on complex models of energy-use trends, estimated emissions of carbon, projected levels of PM, and associated impacts on **mortality.** Each of these models necessarily has several assumptions and includes many uncertainties. Of the many limitations of this exercise, two stand out: we have only calculated **mortality** impacts of PM for adults over age 30 and infants of age 1 month to 1 year; and we do not provide estimates of morbidities related to air pollutants from fossil-fuel combustion. The quantitative estimates of public-health impacts generated through this
assessment should be understood as a first approximation of the likely magnitude of the effect, and not as representing precise predictions of avoided **mortalities.**

With these caveats in mind, if the climate-policy scenario were to be implemented, substantial improvements in fuel efficiency would be realised by 2020, and major reductions in PM pollution would be achieved. By the end of the second decade of the next century, the policy we have outlined here would avoid about 700000 deaths annually (90% CI 385000-1034000), of which 563000 (309000-831000) and 138 000 (76000-203000) would occur in non-annex 1 (developing) and annex 1 (developed) countries, respectively (table 2). Note that the CI only reflects uncertainties in the epidemiological **studies.** If BAU climate policies continue, the greatest impacts will occur in developing countries.

We estimate that implementation of the climate-policy scenario could prevent up to 8 million deaths (90% CI 44-119 million) worldwide during the first 20 years of the next century, corresponding to 167 million (09-25 million) and 634 million (35-94 million) avoided deaths in developed and developing countries, respectively. There are higher expected deaths in developing countries compared with developed countries because of the higher proportional expected changes in PM concentrations under the climate-policy scenario.

To assess the sensitivity of the numbers to certain key assumptions in the estimation of PM concentrations, we considered two analyses. The first assesses the effect of assuming that the USA climate is representative of that in each of the other global regions examined. The second assesses the effects of assuming that there is no change in emission-control levels in the BAU baseline for the non-annex 1 countries and in Eastern Europe and the former Soviet Union. Table 3 presents the results for the cumulative number of deaths avoided under each of these scenarios. If we assume that the climate in the USA is the same in the rest of the world, this results in fewer estimated avoidable deaths than our primary health analysis between 2000 and 2020 in both non-annex 1 countries (38 million vs 63 million in our primary analysis) and annex 1 countries (12 million vs 17 million). The alternative assumption, about control levels in the BAU baseline, results in more estimated avoidable deaths in non-annex 1 countries (76 million vs 63 million).

Discussion

One of the most critical set of assumptions in this scenario assessment is that present levels of PM are causing adverse effects on **mortality** of the magnitude reported by Pope and colleagues. The assumption that fine particles are


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the direct cause of these effects, and not merely correlated with them is also critical to our analysis. It is these fine particles that can be transported globally because they are not trapped by conventional particulate-control technologies, are buoyant, and can travel thousands of miles through the air before they are deposited. Fine PM can produce effects on health in distant countries.

The climate-policy scenario that we use makes several assumptions that affect the estimates of the public-health impact of improved policies for climate control. We assume an ambitious phase-in of pollution-control equipment in developing countries from policies unrelated to the climate-change-mitigation scenarios. If countries fail to use such pollution-control equipment, air-pollutant emissions will increase, and associated deaths and illnesses will be higher than those estimated under the BAU scenario, as seen in the sensitivity analysis. The effectiveness of policies to reduce greenhouse gas in the climate-policy scenario would be even greater. Second, the air-quality modelling protocol we use assumes that the USA distribution of chimney heights is representative of that throughout the world. Many developing countries have lower chimneys for power plants and industrial boilers and greater population densities surrounding industrial facilities, so this assumption probably causes an underestimation of avoided deaths from greenhouse-gas reduction in the non-annex 1 countries. However, if populations are concentrated at greater distance downwind, then lower chimney heights would probably yield lower PM exposures and result in an overestimation of avoided deaths. Third, the analysis does not include reductions in morbidity due to lower PM, or reduc- tions in morbidity from other pollutants.

There are several uncertainties associated with the use of the prospective cohort **studies** for estimation of **mortality** effects from PM exposure worldwide. While the prospective cohort **studies** have attempted to account for all important confounders, some potential confounders may not have been con- sidered. However, sensitivity analyses done in the **study** by Pope and col- leagues found that the association between PM and **mortality** was relatively insensitive to several important potential confounders, including occupational exposure and smoking. This analysis also assumes there is a consistently increasing association between long-term exposure to PM and increased **mortality** risks, which is the same in the rest of the world as it is in the USA. In most developing countries, exposure to PM is an order of magnitude or more higher than that in the USA. Additional increases in **mortality** risks could diminish as exposures approach a saturation level. If the exposure response is not the same at these higher doses, then extrapolation of the USA estimates to developing countries may overestimate the avoided deaths in non-annex 1 countries. The results from the Pope **study,** of adult **mortality,** probably reflect both the effects of long-term and short-term exposure to PM, and there is possibly some overestimation of the annual avoided **mortality** associated with estimated annual decrements in PM. Another factor that could lead to overestimation is that PM levels in the USA have generally improved over the past few decades, especially for coarse particulate levels. If the premature **mortality** effects are related to cumulative exposure over a long period, then the observed effects in the Pope **study** could be associated with a larger PM change than observed (leading to a smaller risk per unit change).

Our analysis accounts for the age-distribution of the populations affected. If the RR is higher for older people, then the analysis could overestimate


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**mortality** effects in non-annex 1 countries. However, the younger populations of developing countries must often confront other health threatening condi- tions (eg, malnutrition), which may increase their vulnerability to pol- lutants. Estimates of the percentage of cardiorespiratory deaths in non-annex 1 countries (except for subSaharan Africa) is similar to that in annex 1 countries, indicating that it is reasonable to apply PM associations found in the USA to other countries. While we are not aware of any attempt to replicate the **study** by Woodruff and colleagues, similar results of infant **mortality** associated with PM have been found in the Czech Republic.40

The quantification of **mortality** benefits derived from our analysis only con- siders outdoor sources of PM from fossil-fuel combustion. For many countries around the world, burning biomass indoors can also be an important source of PM.
For example, in China, households burn about 500 million tons of biomass fuels for cooking and heating each year.44 The suspended PM in Chinese households often exceeds recommended air-quality guidelines by WHO by more than tenfold.45 For most of the Chinese population, the health impacts from indoor exposure to air pollutants greatly exceed that of workplace or outdoor exposure. Data from a series of **studies** and official disease statistics sug- gest that air pollution from both indoors and outdoors is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide.46

In 1990, lower-respiratory-infections were the leading components of dis- ability adjusted life years.47 By 2020, respiratory-related diseases are projected to rank among the top ten causes of poor health in the world. The total number of annual deaths that could be avoided under the climate-policy scenario in 2020 in much of the developed world almost equals the projected number of fatal injuries caused by automobile accidents.48 In the USA, by the year 2020, at least 33000 deaths a year could be avoided from implementation of the climate-policy scenario. This projected number of avoidable deaths in the USA is of the same order of magnitude as currently occurs as a result of several major causes of death from illnesses, each of which is subject to major public-policy interventions, including human immunodeficiency and chronic liver diseases.

Newspaper reports this year from Sumatra, Borneo, and other regions49 indicate that measured levels of air pollution associated both with burning forests and air pollution from energy production sometimes exceed the levels measured in London during the killer fog of 1952. This episode of elevated pollution in London was associated with nearly 3000 excess deaths in 1 week.50

Health patterns in any region reflect an intricate combination of factors: poverty, nutrition, population density, housing and sanitation, smoking, and workplace and environmental factors. While environmental factors cannot account for all these patterns, they are important because they can be changed by public policy. Patterns of rapid growth and development in emerging mega-cities of the developing world can impose significant involuntary risks from air pollution on large proportions of their population.51,52 Control or prevention of this exposure needs to be recognised as critical to the develop- ment of environmental and public-health policy. Even if environmental factors pose relatively small risks of common ailments, but the exposure is widespread and vulnerable groups exist in the exposed population, the public-health impact of air pollution can be significant. Where exposure is universal and where the


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population is vulnerable the marginal contribution of air pollution can be significant.53

Conclusion

Regardless of how or when greenhouse gases alter climate,54 reducing them now will save lives worldwide by lessening particulate air pollution. The beneficial effects of reduced particulate pollution appear to be far greater in rapidly developing countries than in developed countries, although they are substantial in both regions. The overall scientific challenge is to discern enough from present and past trends to reduce uncertainties, so that an integrated impact assessment can yield useful results. Our analysis should not be misconstrued as precise predictions, but as relative indicators of the magnitude of the effects that are likely to arise under conditions that we have specified in these climate-related scenarios.

The transdisciplinary activity pursued in this assessment provides a systematic framework for the estimation of potentially far-ranging and substantial health impacts in an uncertain future world. This estimate looks beyond the restricted view of environmental health as a local problem,55 recognising the truly global reach of climate policies. There is a dynamic between being able to predict future impacts and being able to affect policies to avoid those potential impacts. In the 18th century, the philosopher Saint-Simon noted "savoir pour prevoir" and "prevoir pour pouvoir". With knowledge comes the ability to predict. With the ability to predict, comes the power to change those predictions.

Contributors

Devra Lee Davis, World Resources Institute (WRI); Tord Kjellstrom and Rudi Slooff, World Health Organization; and Albert McGartland, Environmental Protection Agency (EPA) organised this **study.** Analyses were provided by Dwight Atkinson, Wiley Barbour, William Hohenstein, Peter Nagelhout, and Tracey Woodruff, EPA; Frank Divita and Jim Wilson, Pechan Associates; Leland Deck, Abt Associates; and Joel Schwartz, Harvard University School of Public Health. All contributed to the writing of this report.

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GRAPHIC: Table; Chart; Graph; Illustration

LANGUAGE: ENGLISH

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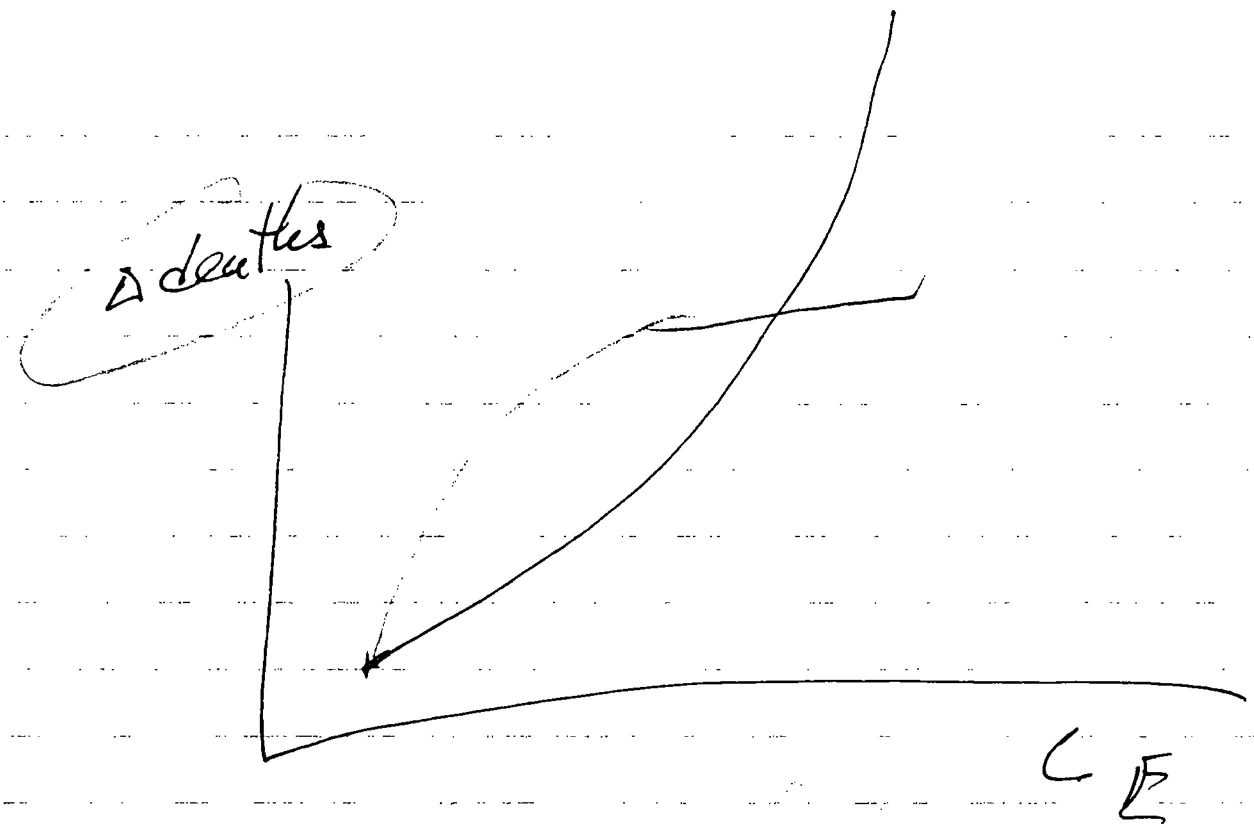
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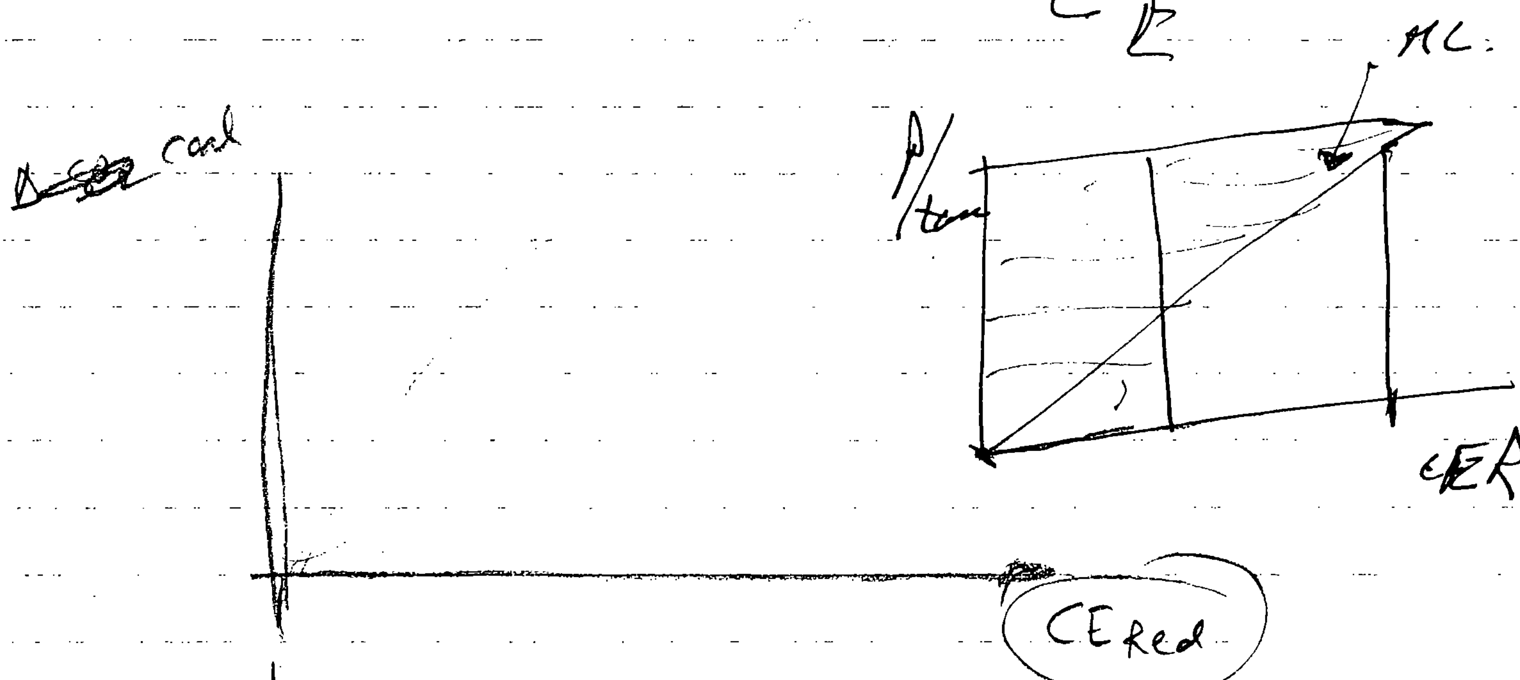
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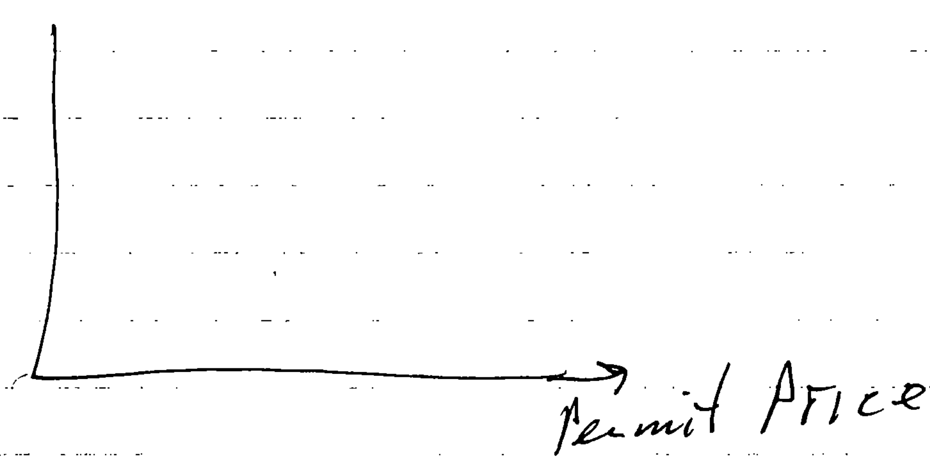
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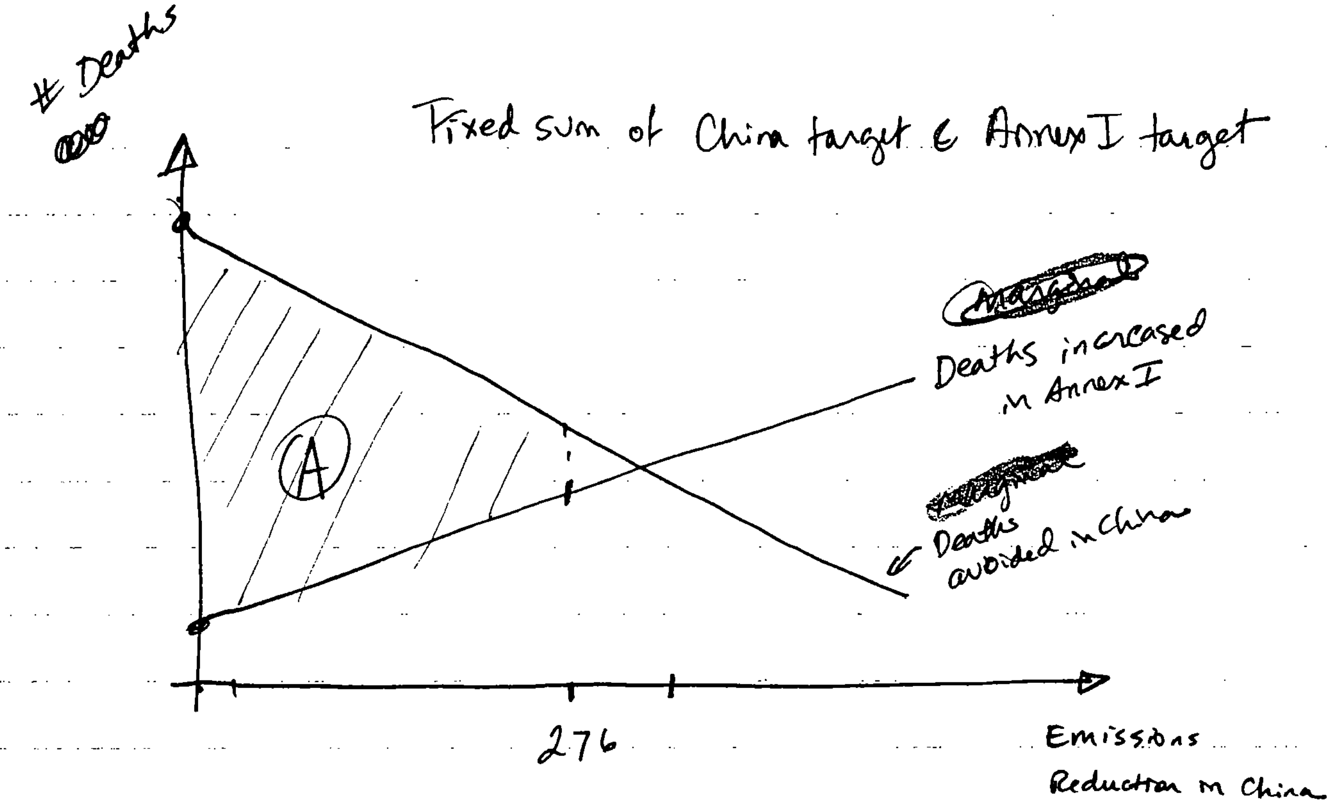
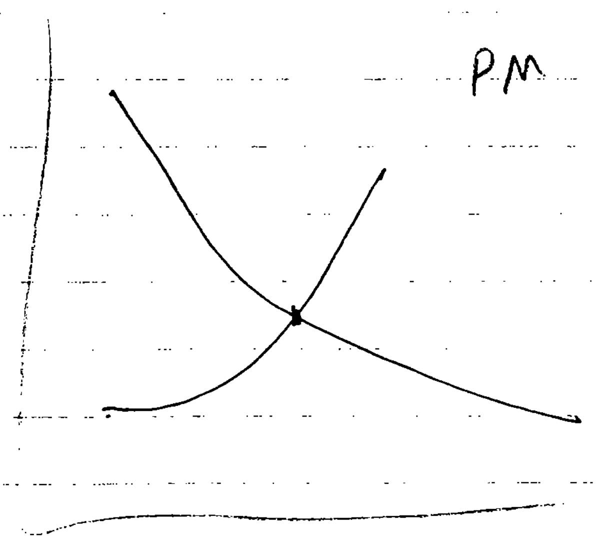
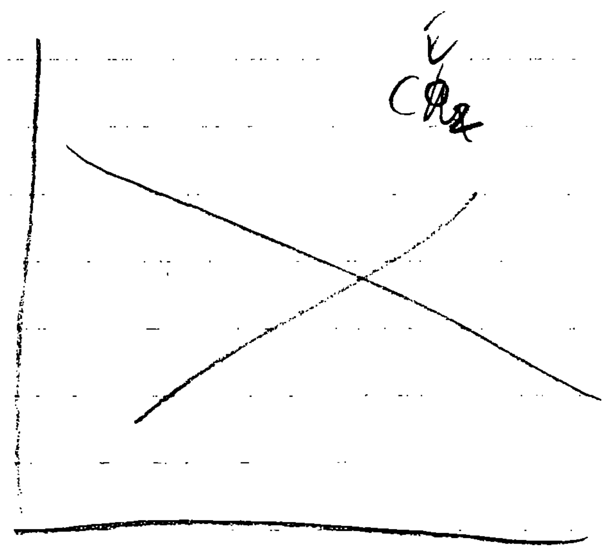



A = total annual ~~avg~~. deaths avoided from C&T ~~idea~~ vs. Annex I only

same GHG effect



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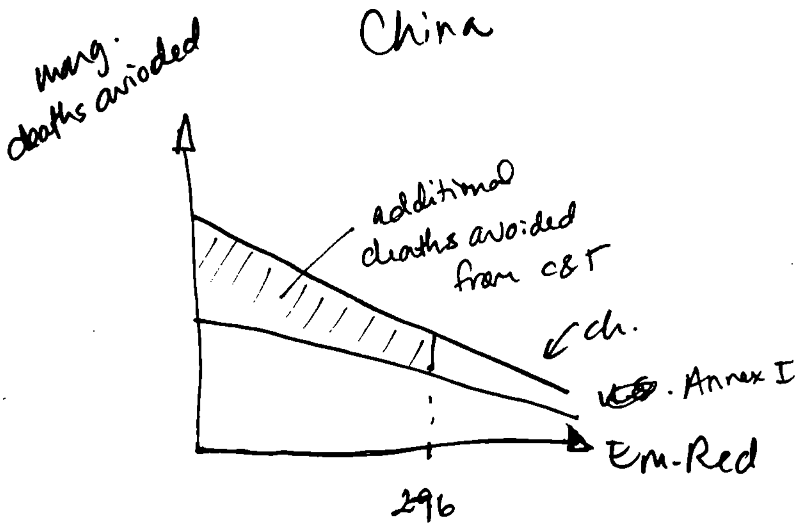
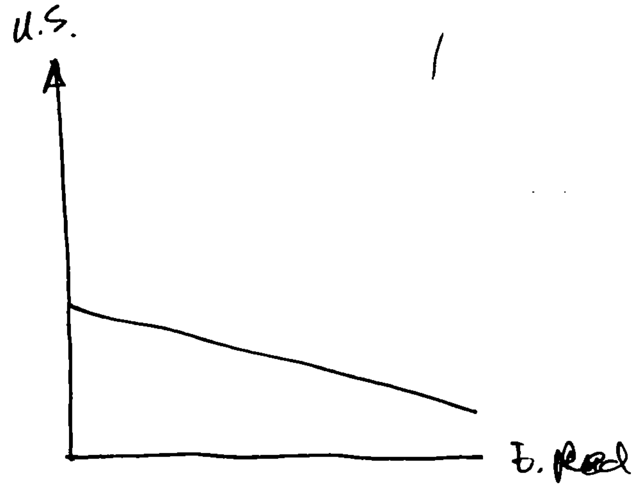
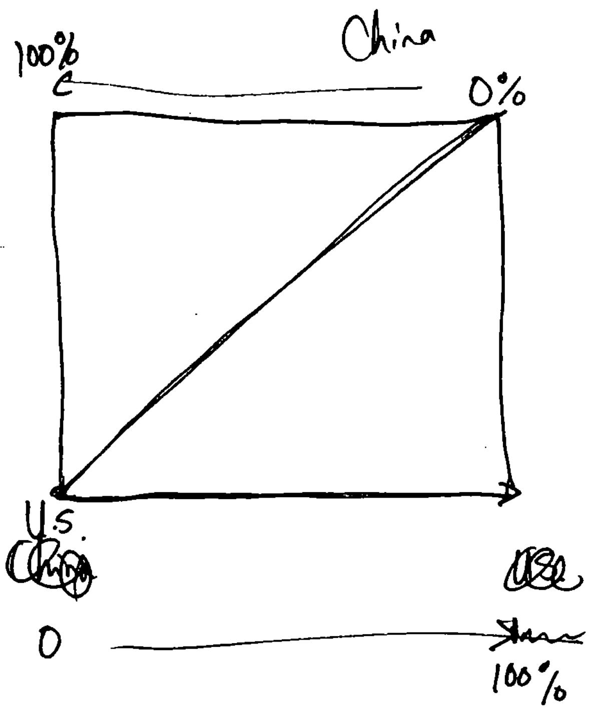
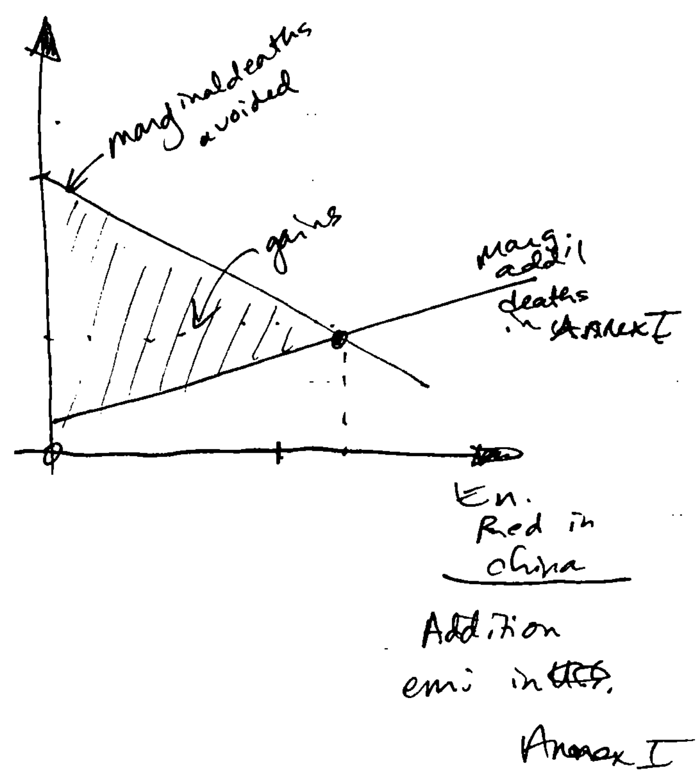



Annex I
Total emissions = ~~US~~ target
+ China target

**Ancillary benefits of non-Annex I cap and trade**

The reduction of greenhouse gas emissions achieved by developing countries under a cap and trade system will reduce simultaneously the concentrations of numerous other hazardous air pollutants, producing ancillary environmental and human health benefits. A recent study in the journal *Lancet* projects that by 2020, a climate change policy scenario in which developing countries reduce emissions to 10% below their BAU and developed countries reduce emissions to 15% below their 1990 levels could produce an annual reduction of 700,000 deaths by reducing airborne particulate matter (PM). Non-Annex I countries experience 563,000 of those avoided deaths. The estimations in the *Lancet* study can be adapted to estimate the deaths avoided by the emissions reductions charted in this paper.

Key assumptions in Lancet:
Earlier estimates of mortality risk associated with PM are correct.
Mortality risk associated with PM is the same around the world as it is in US.
PM reductions are proportional to emissions reductions.

Key assumptions here:
All net DC emissions reductions are from reduction in gross emissions, not increases in sinks.
Deaths avoided in a particular developing countries is equal to the total non-Annex I deaths avoided multiplied by its share of the non-Annex I population.

| Trading Scenario | U.S. MMTCE reduction | U.S. PM deaths avoided | LDC % reduction from BAU | LDC population | LDC MMTCE reduced | LDC PM deaths avoided |
|---|---|---|---|---|---|---|
| Annex I only | | | 0% | 0 | 0 | |
| Annex I + China | | | 20% | 1,357,627,000 | 276 | |
| Annex I + India | | | 18% | 1,140,563,000 | 65 | |
| Annex I + Mexico | | | 19% | 113,385,000 | 34.5 | |

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Scenario | Permit Price | | CO2 Reductions (MMTC) | | |
| 2 | | 97$ | 92$ | US | W'ern Eur | E'ern Eur |
| 3 | A1 | 54 | 48 | 202 | 97 | 31 |
| 4 | A1+China | 26 | 23 | 101 | 49 | 15 |
| 5 | A1+India | 47 | 42 | 178 | 84 | 27 |
| 6 | A1+Mexico | 51 | 45 | 191 | 91 | 29 |

| | G | H | I | J | K | L | | |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | A1 Total | A1-US |
| 2 | FSU | Canada | Japan | Australia | China | India | | |
| 3 | 189 | 15 | 24 | 12 | | | 570 | 368 |
| 4 | 108 | 8 | 12 | 7 | 276 | | 300 | 199 |
| 5 | 169 | 13 | 21 | 11 | | 66 | 503 | 325 |
| 6 | 179 | 14 | 23 | 12 | | | 539 | 348 |

| | M |
|---|---|
| 1 | |
| 2 | Mexico |
| 3 | |
| 4 | |
| 5 | |
| 6 | 34 |

Lancet

| | BAU | Policy |
|---|---|---|
| Annex I | | 15% below 1990 levels |
| Non-Annex I | | 10% below BAU |

<u>Mortality only</u>

- PM < 10 m
- PM < 25 m ?

IPCC Atmospheric Stab. Framework (ASF) model
⇒ trajectories of carbon emissions

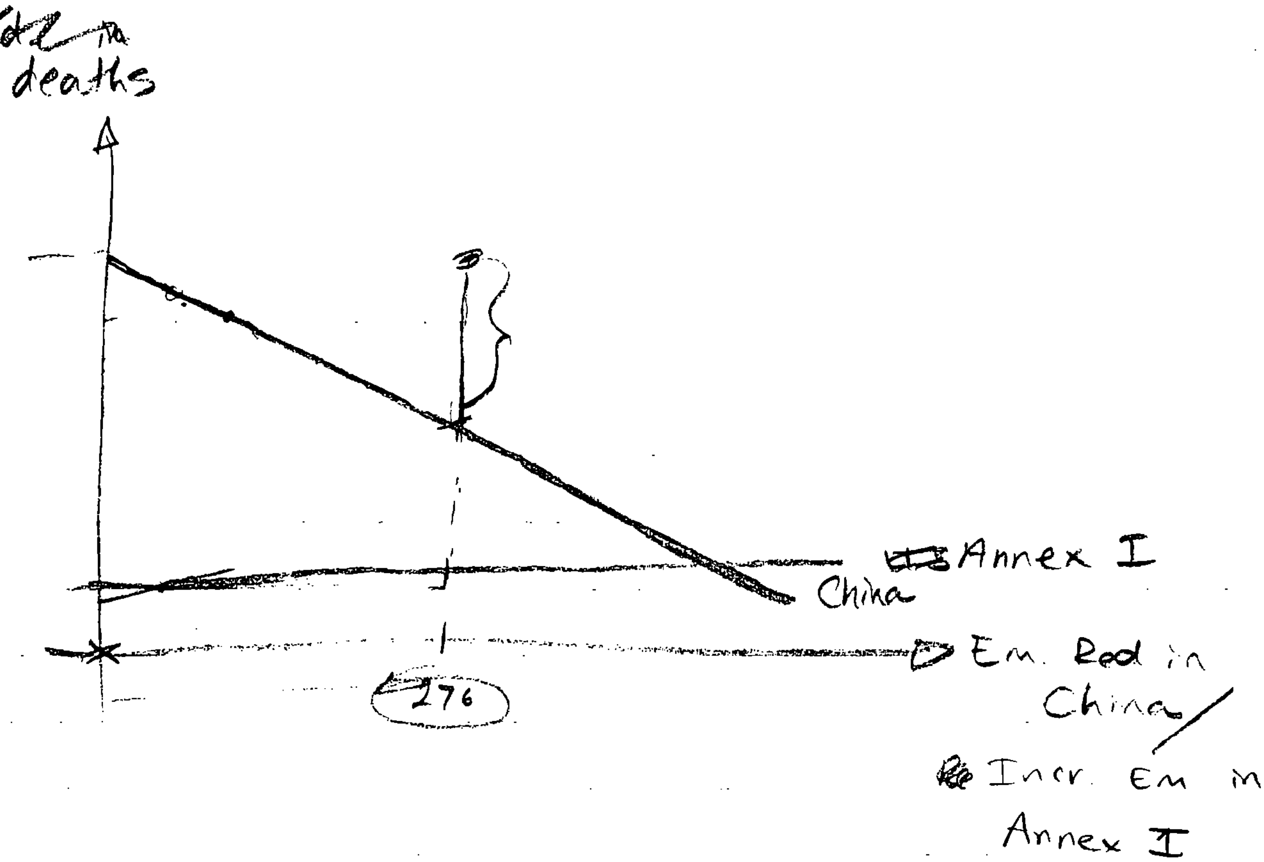
Baseline $CO_2$ emissions Scenarios

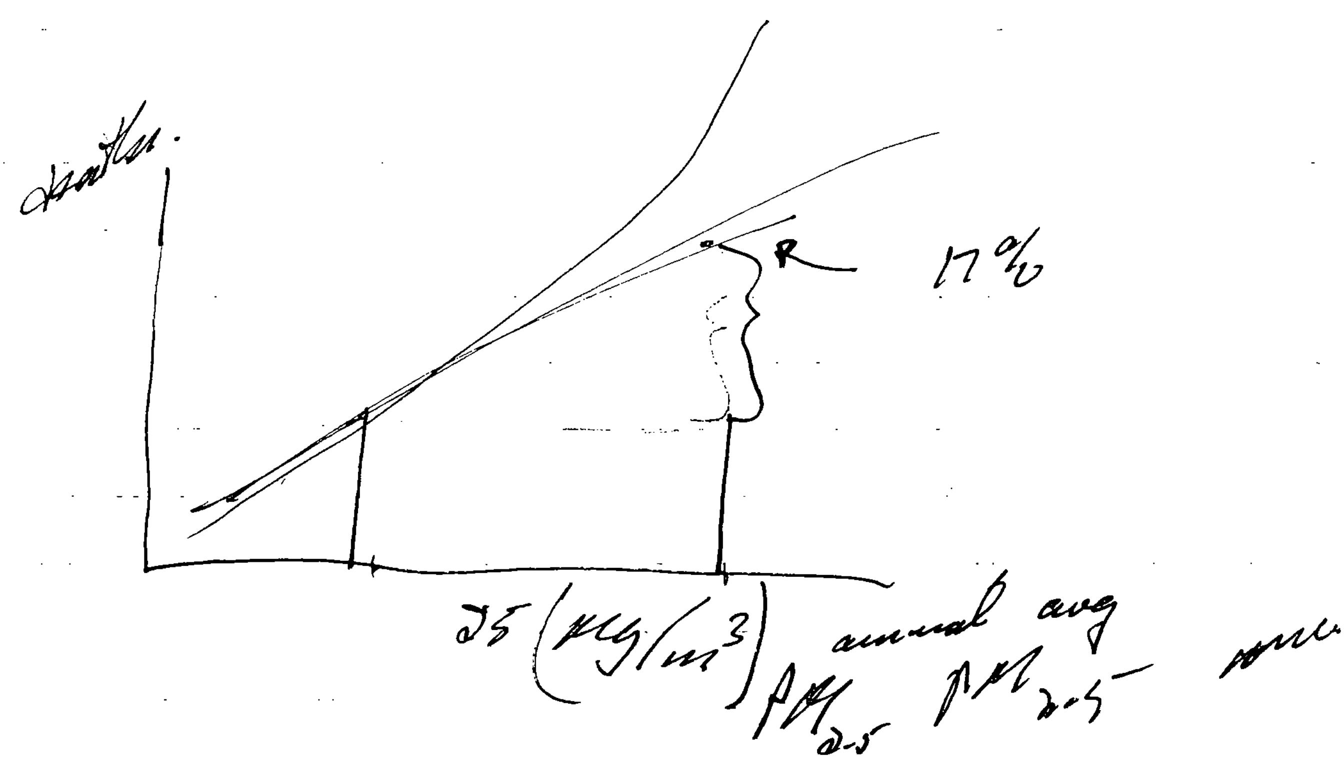
| | | |
|---|---|---|
| 2010 | 83 billion tons in paper | (88 = EIA est.) |
| 2020 | 107 " " " " | (84 in IIASA/WEC) |
| | | (105 in Shell Oil) |

Spatial ~~dist~~. assoc. btwn source & pop is same worldwide as in U.S.

No est. of indoor PM.

Base




$$\frac{\Delta d}{\Delta PM^c} = \frac{17\%}{25}$$

C emission → Non-carbon emission → $PM_{2.5}$ annually → deaths

policy implementation

- geographic
- airchemistry

- dose response

Jeffrey A. Frankel
03/30/98 08:21:19 AM

Record Type: Record

To: Joseph E. Aldy/CEA/EOP, Randall W. Lutter/CEA/EOP, Adele C. Morris/CEA/EOP

cc: Lisa D. Branch/CEA/EOP

Subject: our paper on LDC commitments

I've marked moderate revisions. Will send around. Ask me anything unclear. Otherwise, it's fine with me to circulate. (But perhaps we should run it by Janet again?)

JF

I'd like Sections IV & V to be Appendices. That's not a comment on their quality; they are good. But I don't want them to detract from our main pts. ok?

**A Proposal for Developing Countries:**
**Participation in a "Target and Trade" System**

**I. As the U.S. moves ahead in the post-Kyoto process, and seeks to elicit developing country participation, we must identify leading opportunities for constructive engagement. To that end, this analysis demonstrates that, if developing countries (a) accept binding targets at or slightly below their business as usual (BAU) emissions levels, and (b) trade from their respective targets, the gains will be substantial. Developing countries will benefit from additional income, the U.S. (and other Annex I countries) will benefit from lower costs, and the environment will benefit from further reductions in emissions. The strongest case for eliciting developing country participation may be found, ultimately, in persuading them of the substance of the gains from trade. To the extent that we can convince them that they will benefit from participating in a "target and trade" system, we can better draw them into the post-Kyoto process. We believe that participation in a "target and trade" system should be the cornerstone of our international negotiations.**

~~A~~. The economic and environmental rationale for such participation includes

- **Greater economic benefits to developing countries:** With targets at or only slightly below BAU, developing countries would enjoy net gains of many billions of dollars through the international sale of emission reductions achieved at lower cost than the world price.

- **Greater cost savings to the U.S.:** Participation by developing countries in international permit markets would greatly lower the costs to the U.S. of meeting its Kyoto target (as CEA testimony showed). In particular, costs would be lower than with trading among only Annex I countries.

- **Greater environmental benefits:** Targets slightly below business as usual would lower global emissions relative to a world with only Annex I targets. ~~and m~~ Most importantly, even targets at BAU would ~~reduce~~ limit the potential for emissions leakage ~~associated with~~ arising from lower world oil prices or with relocation of energy-intensive manufacturing from industrialized to developing countries. Further, reducing carbon dioxide emissions generates ancillary air quality benefits through lower particulate matter, sulfur dioxide, and nitrogen oxides emissions.

- **Target and trade yields greater benefits than CDM:** While the Clean Development Mechanism will likely result in cost savings to the U.S. relative to a world with only Annex I trading, a system including effective target and trade of developing countries' emissions would yield much greater cost savings to the U.S. and greater gains to developing countries than CDM. Further, target and trade could achieve environmental benefits not achievable by pursuing CDM, which only redistributes emissions geographically.

Make it last bullet

Title maybe "The principle of full participation"

- ~~8~~. Other rationales include the long-run benefits of including developing countries into global negotiations, for example, as recognized by the Byrd-Hagel resolution. By establishing participation now, further commitments might be feasible in future periods.

**II. Problem:** To persuade a developing country *voluntarily* to adopt a target and then to trade permits internationally, international agreements must be structured to reduce the risk of inadvertent stringency and in particular to reduce the possibility of a target so stringent as to cause large economic losses to the developing country.

**Proposed Solution: Negotiations should focus on ~~slight reductions~~ from the estimated business as usual emissions level, where this level is expressed in a way that depends on the *future* values of economic variables, such as GDP.**

I don't want to say reductions. But, as written, the phrase diverts the reader from the point.

Rationale: Such targets would avoid the risk of inadvertent stringency associated with higher than projected economic growth between now and the beginning of the commitment period in 2008. (Developing countries would face only the much smaller risk that emissions would be higher than expected, *given* the economic conditions realized in 2007.)

This point is too prominent up here. Move farther down. ("2008 vs 2007" is much less important than "2007 info vs 1997 info")

Basic principles for implementing such an approach are:

- **Reasonable Forecasts**: The relationship between the target (putting aside ~~ignoring~~ any real reductions in emissions) and the values of economic variables, when applied to emissions and such variables during recent years, should predict emissions reasonably well ~~(~~and be without demonstrable statistical bias~~)~~. Relationships that give reasonably reliable predictions reduce the risk of either, on the one hand, inadvertent stringency or, on the other hand, paper tons which could increase global emissions.

under "predetermined targets"

- **Predetermined Targets:** ~~The~~ Yr target ~~should not depend on~~ contemporaneous values of economic variables, ~~so as~~ to avoid uncertainty during the commitment period ~~about the country's target~~. For example, the target should not vary with 2008 or 2010 GDP levels, but rather with 2007 GDP.

- **No Perverse Incentives:** The target should depend on values of economic variables only indirectly related to emissions, to avoid creating perverse incentives for developing countries to increase emissions so as to have higher targets in the commitment periods. For example, the target should not depend on energy consumption in 2007, but could reflect pre-Kyoto emission levels.

**III. Illustration:** One way of implementing ~~the solution is described~~ below. Other ways of implementing the solution may work as well or better. The conclusions are stated below, ~~and~~ the details of our work follow in an appendix [or "addendum" or supplementary pages"]

- Defining the business as usual level for a developing country as a function of its GDP and population in earlier years and setting the emissions target at that level yields a relatively only a small ~~negligible~~ risk of leaving the developing country worse off under target and trade because of inadvertent stringency. Even A target ~~only~~ slightly below BAU would also yield ~~negligible~~ small risk of leaving the developing country worse off.

- Emissions targets for developing countries set below their business as usual emission level would of course result in gains from trade ~~lower~~ smaller than with a BAU target, ~~though~~ while providing environmental benefits. The higher costs of a target set below BAU are borne by both the developing countries and the Annex I countries.

*There are significant gains from trade for developing countries and large cost-savings to the U.S. ~~if even one large developing country~~ accepts an emissions target at BAU and participates in emissions trading. Table 1 and Charts 1 through 3 illustrate these gains from trade from a baseline of full Annex I trading.*

italics

"Negligible" seems too strong. All kinds of unexpected developments are possible. E.g. what if a country discovers large new oil deposits?

Table 1. Illustrative Gains from Trade with Developing Countries that Target and Trade

| Trading Scenario | Permit Price1 (1997$/ton) | Country Gaining | Gains from Trade with Developing Countries |
|---|---|---|---|
| Annex I only | $54 | United States | not applicable |
| Annex I + China | $26 | China | $3.6 billion/year |
| | | United States | $11.6 billion/year2 |
| Annex I + India | $47 | India | $1.6 billion/year |
| | | United States | $2.5 billion/year2 |
| Annex I + Mexico | $51 | Mexico | $0.9 billion/year |
| | | United States | $1.2 billion/year2 |

1 These scenarios do not account for the cost savings available through the Clean Development Mechanism and carbon sinks.
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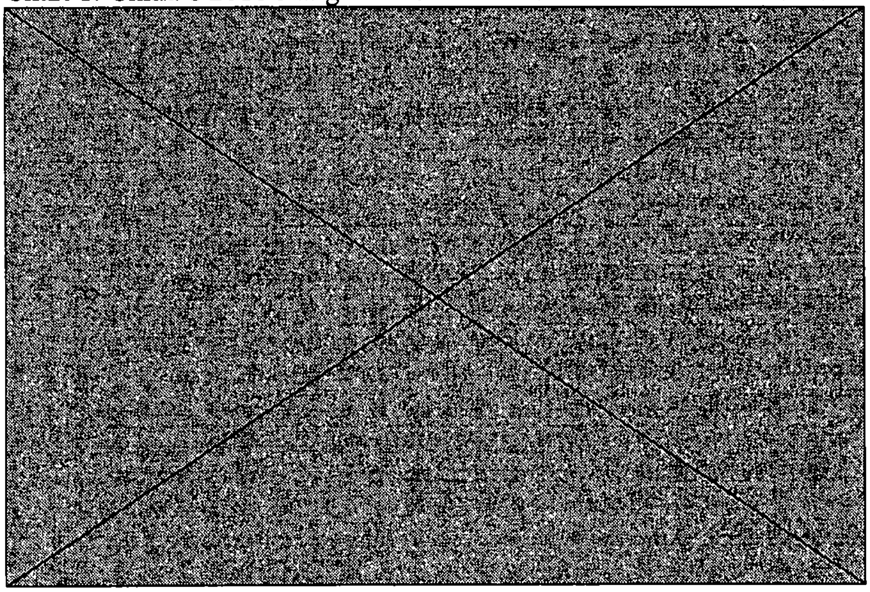
Chart 1. China's 2010 Marginal Abatement Cost Curve and Gains from Trade



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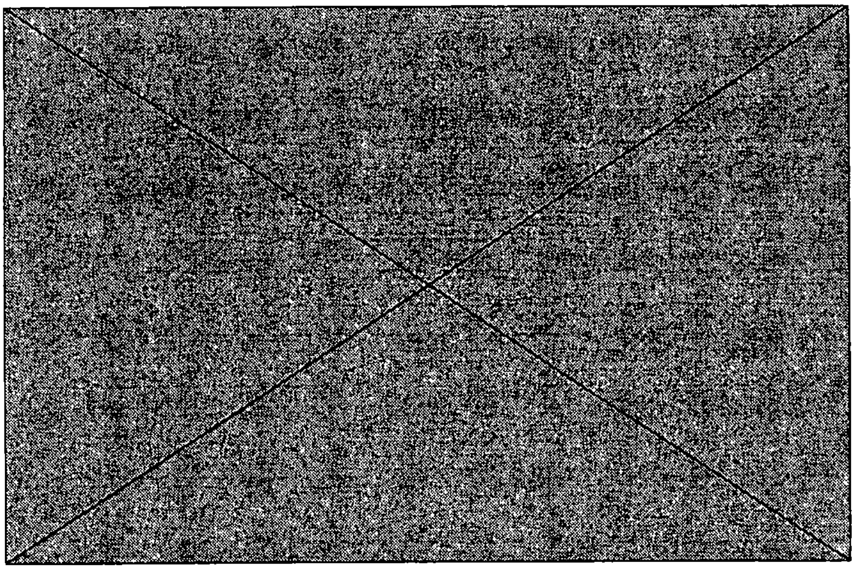

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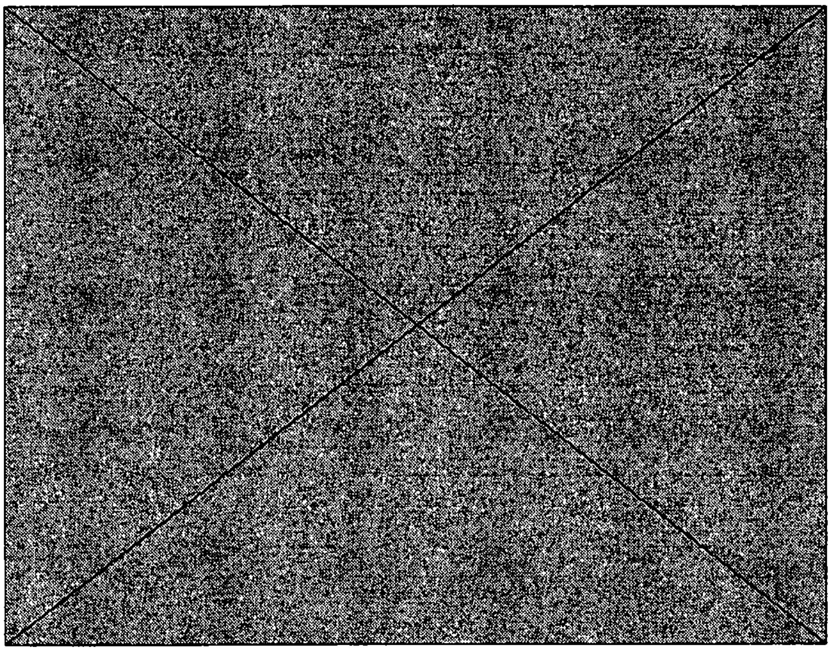


[The point made below is only a small part of the discussion that would be needed in a section with the title you have given.]

[And what is our motivation for making this point at all here? Altho it is completely valid, it may work to undermine our main point. E.g., The point is less useful than Adele's point re Ancillary Benefits in V. But I think it both (maybe should) go in Appendices & so should go after it. to avoid detractg.. from our main points.

Appendix II ~~An~~ A Little-Noticed Effect of Setting Below BAU

**~~IV~~. ~~How Far Below BAU Should the~~ Developing Countries' Targets ~~Be Set~~?**

among (?)

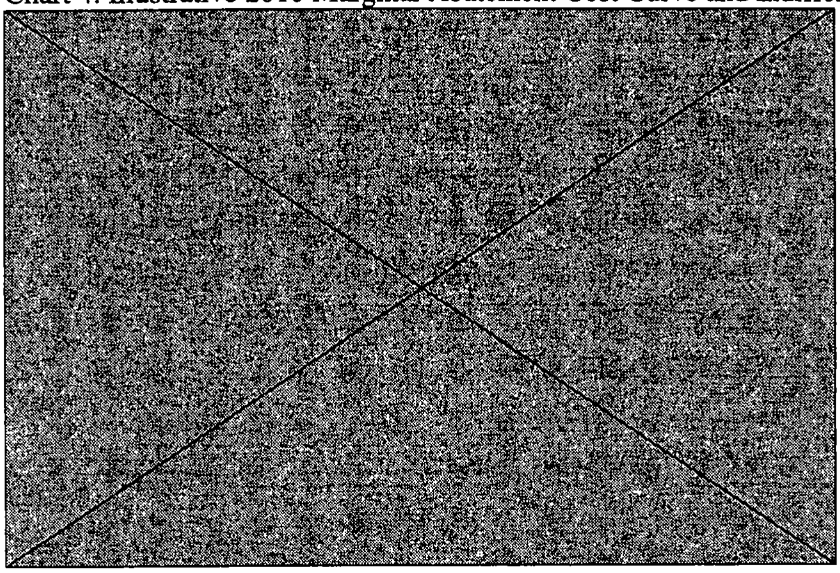
The answer to this question has many dimensions. Most commonly discussed is the issue of fairness: what commitments to reduce emissions should be made by countries whose economic resources differ substantially? Generally neglected, but discussed below, is the issue of efficiency. In particular, what are the implications for U.S. costs of increasingly more stringent targets on emissions from key developing countries?

The environmental gains from more comprehensive cuts in global emissions come at the price not only of economic costs incurred by a developing country that signs up for cuts, but also economic costs by Annex I countries.

More stringent developing country targets raise U.S. costs by restricting the supply of permits in world markets and so raising the price of permits.

To assess the magnitude of this effect consider the target which just leaves a country no better off than no target at all. This "indifference" target is where the costs of meeting the target just equal the net gains from selling permits in world markets. Chart 4 illustrates gains from trade for a small country. For a target that is equivalent to a reduction from BAU of 17 MMTC, net gains from foreign exports are B, and the cost of meeting the target is C. Since B = C in this example, the net gains from trade are nil.

Chart 4. Illustrative 2010 Marginal Abatement Cost Curve and Indifference Target



Note: For simplicity, This indifference target is illustrated for a country whose participation in world permit markets does not affect world permit prices.

Table 2 provides an illustration of the effects of emissions targets more stringent than BAU on China with Annex I plus China trading. Note that a small reduction below BAU has no real effect on the Annex I trading price, and thus no economic effects on the U.S. However, as the target becomes more stringent, the Annex I trading price increases, resulting in higher total costs of compliance for the U.S. If China accepts a target below BAU, the cost of this additional stringency to the U.S. -- essentially, the cost of supplying the environmental benefits associated with these emissions reductions -- can become significant. Thus developing country participation in the form of acceptance of targets more stringent than business as usual will raise costs to the U.S.

Table 2. Effects of Various Chinese Emissions Targets with Annex I Trading

| Emissions Target1 | Permit Price (1997$/ ton) | Chinese Emissions Reductions (MMTC) | Chinese Emissions Sales (MMTC)2 | Total Cost to U.S. of Complying with Kyoto | Cost to U.S. of Additional Stringency |
|---|---|---|---|---|---|
| BAU | $26 | 276 | 276 | $13.4 b | not applicable |
| BAU - 1% | $26 | 276 | 262 | $13.4 b | ~$0 |
| BAU - 5% | $29 | 304 | 235 | $14.9 b | $22/ton |
| Indifference | $36 | 343 | 172 | $17.9 b | $26/ton |

1 We employ the SGM BAU for China for the purposes of these calculations.
2 Reductions in Chinese emissions less Chinese emissions sales yields net global reductions.

Imposing this "indifference" target on China, given that its participation lowers world permit prices, leads to the following conclusions.

- An indifference target for China increases annual U.S. costs by $4.5 billion or 33% relative to a BAU target for China.

- If China accepts an emissions target requiring reductions of approximately 170 MMTC below BAU, the average cost to the U.S. would be $26/ton. This is not the average cost of a ton of emissions purchased from China, but the average cost to the U.S. of the environmental benefits associated with China complying with a more stringent target.

- The environmental benefit that would be purchased at the above price is a cut of _% in global emissions (per year in 2008–2012), beyond the _% cut agreed at Kyoto.

## Appendix 1 V. Ancillary Environmental Benefits of Target and Trade in Developing Countries

The voluntary reduction of greenhouse gas emissions by developing countries under a target and trade system will simultaneously reduce emissions of several pollutants, producing ancillary environmental and human health benefits in those countries. ~~The~~ environmental and health benefits that accrue to ~~those~~ there developing counties ~~are unlikely to be offset by~~ cause decreases in environmental quality in the United States because of our strict health-based air quality standards. This transfer of pollution is unlikely to materialize, however, would be offset by the "minus" of

A recent study in *Lancet* examines the emissions of one pollutant that are reduced along with carbon emissions: airborne particulate matter (PM). The study projects that by 2020, a climate change policy scenario in which developing countries reduce emissions to 10% below their BAU could produce an annual reduction of 563,000 statistical deaths "there" [or "worldwide"?]

[because selling pollution rights is immoral?]

The analysis below adapts the predictions in the *Lancet* study to estimate the mortality risk reduced from participation by three developing countries (China, India, and Mexico) in a target and trade system. These illustrative calculations take as given the emissions reductions from BAU resulting from permit sales that are predicted by SGM. It suggests that significant

One might think that when the U.S. purchases emissions rights from developing countries, the "plus" of public health gains could result from developing country participation in international carbon permit markets.

Table 3. The Effects of International Carbon Permit Trading on Mortality Risk Associated with Particulate Matter Emissions

| Country | Predicted carbon emissions reduction from international permit sales | Share of non-Annex I population in 2010 | Annual PM statistical deaths avoided in 2010 by international carbon permit trading |
|---|---|---|---|
| China | 20% | 23.7% | 136,700 |
| India | 18% | 20.3% | 105,300 |
| Mexico | 19% | 2.0% | 19,700 |

This is unclear. Either explain or drop.

Note that for most developing countries, adopting a carbon target more stringent than BAU and participating in international trade does not yield any additional ancillary benefits than a BAU target.

Caveats

Major assumptions beyond those in the *Lancet* article include:

- Deaths avoided in each non-Annex I country are proportional to the country's share of non-Annex I population.
- Deaths avoided are proportional to carbon emissions reductions.
- Each key developing country is the sole non-Annex I country to adopt a target and participate in international trading.

## Summary of Analysis

A. Data

We have compiled data on 3 variables: emissions of carbon dioxide, GDP, and population for 117 countries for the time period 1970-1992. The carbon dioxide emissions data, measured in millions of metric tons of carbon, are from the Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory, DOE). The GDP data, measured in 1987 U.S. dollars, are from the World Bank. The population data, measured in thousands of individuals, are from the United Nations Population Division.

B. Methods

We have estimated a fixed effects linear regression on the logs of these variables, for the countries in our data set, excluding those listed in Annex I. Our regression uses four non-overlapping 5 year intervals for each country. Our forecasts include the country specific constants.

C. Results

The fixed effects regression we estimated is Why not drop this?

Emissions = a GDPt-1 + b GDPt-2 + c Populationt-1 + $\gamma$ trend

Emissions are the natural logarithm of the five year non-overlapping average of carbon emissions. All independent variables are lagged. GDPt-1 is the log of the gross domestic product in the year prior to the first year in the emissions variable, GDPt-2 is GDP in the year two years prior to the first year included in the emissions variable, and populationt-1 is the country's population in the year prior to first year included in the emissions variable. Trend is one in the first 5 year period, and 2, 3, and 4 respectively in the subsequent 5 year periods. The useable data included 376 cross-section time series observations. The fixed effects regression used 98 degrees of freedom. The R squared was in excess of 0.99.

Misleading? Is much of this fixed effects?

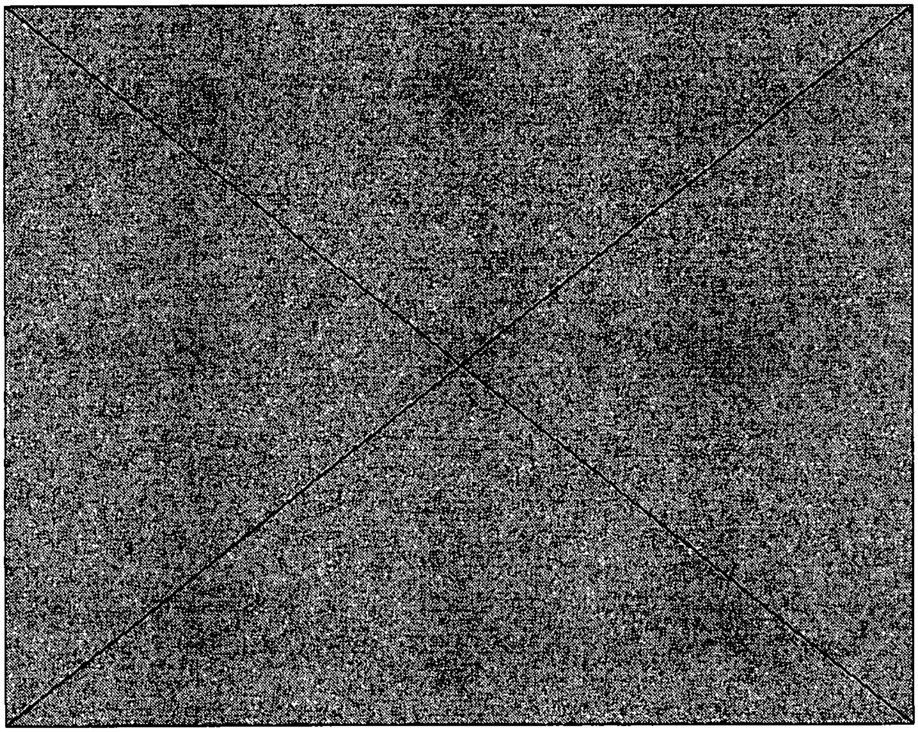
How about including 10-year-lagged emissions?
(maybe instead of fixed effects?)

Table 4. Model I Results

| Variable Name | Coefficient Estimate | Standard Error |
|---|---|---|
| GDPt-1 | 0.9501823 | 0.2443047 |
| GDPt-2 | -0.411297 | 0.23894 |
| Populationt-1 | 0.4836006 | 0.2055439 |
| trend | 0.0073712 | 0.0310638 |

As one illustration of the model's accuracy in predicting emissions, consider the chart below that maps actual and predicted emissions using within sample data for ten selected developing countries. The predicted value is never more than 1/4 of one percent away from the actual emissions average for any of the five year intervals.

Chart 5. Error in Model I Prediction as a Fraction of Actual Emissions



## A Proposal for Developing Countries: Participation in a "Target and Trade" System

**I. As the U.S. moves ahead in the post-Kyoto process, and seeks to elicit developing country participation, we must identify leading opportunities for constructive engagement. To that end, this analysis demonstrates that, if developing countries (a) accept binding targets at or slightly below their business as usual (BAU) emissions levels, and (b) trade from their respective targets, the gains will be substantial. Developing countries will benefit from additional income, the U.S. (and other Annex I countries) will benefit from lower costs, and the environment will benefit from further reductions in emissions. The strongest case for eliciting developing country participation may be found, ultimately, in persuading them of the substance of the gains from trade. To the extent that we can convince them that they will benefit from participating in a "target and trade" system, we can better draw them into the post-Kyoto process. We believe that participation in a "target and trade" system should be the cornerstone of our international negotiations.**

A. The economic and environmental rationale for such participation includes

- **Greater economic benefits to developing countries:** With targets only slightly below BAU, developing countries would enjoy net gains of many billions of dollars through the international sale of emission reductions achieved at lower cost than the world price.

- **Greater cost savings to the U.S.:** Participation by developing countries in international permit markets would greatly lower the costs to the U.S. of meeting its Kyoto target (as CEA testimony showed). In particular, costs would be lower than with trading among only Annex I countries.

- **Greater environmental benefits:** Targets slightly below business as usual would lower global emissions relative to a world with only Annex I targets, and most importantly, would reduce the potential for emissions leakage associated with lower world oil prices.

- **Target and trade yields greater benefits than CDM:** While the Clean Development Mechanism will likely result in cost savings to the U.S. relative to a world with only Annex I trading, a system including target and trade of developing countries' emissions would yield greater cost savings to the U.S. and greater gains to developing countries than CDM. Further, target and trade could achieve environmental benefits not achievable by pursuing CDM, which only redistributes emissions geographically.

B. Other rationale include the long-run benefits of including developing countries into global negotiations, for example, as recognized by the Byrd-Hagel resolution. By establishing participation now, further commitments might be feasible in future periods.

**II. Problem:** To persuade a developing country *voluntarily* to adopt a target and then to trade permits internationally, international agreements must be structured to reduce the risk of inadvertent stringency and in particular to reduce the possibility of a target so stringent as to cause large economic losses to the developing country.

**Proposed Solution: Negotiations should focus on slight reductions from the estimated business as usual emissions level, where this level is expressed in a way that depends on the *future* values of economic variables, such as GDP.**

Rationale: Such targets would avoid the risk of inadvertent stringency associated with higher than projected economic growth between now and the beginning of the commitment period in 2008. Developing countries would face only the much smaller risk that emissions would be higher than expected, *given* the economic conditions realized in 2007.

Basic principles for implementing such an approach are:

- **Reasonable Forecasts**: The relationship between the target (ignoring any real reductions in emissions) and the values of economic variables, when applied to emissions and such variables during recent years, should predict emissions reasonably well (and be without demonstrable statistical bias). Relationships that give reasonably reliable predictions reduce the risk of either inadvertent stringency or paper tons which could increase global emissions.

- **Predetermined Targets:** The target should not depend on contemporaneous values of economic variables, so as to avoid uncertainty during the commitment period about the country's target. For example, the target should not vary with 2008 or 2010 GDP levels, but rather with 2007 GDP.

- **No Perverse Incentives:** The target should depend on values of economic variables only indirectly related to emissions, to avoid creating perverse incentives for developing countries to increase emissions so as to have higher targets in the commitment periods. For example, the target should not depend on energy consumption in 2007, but could reflect pre-Kyoto levels.

**III. Illustration:** One way of implementing the solution is described below. Other ways of implementing the solution may work as well or better. The conclusions are stated below and the details of our work follow.

- Defining the business as usual level for a developing country as a function of its GDP and population in earlier years and setting the emissions target at that level yields a negligible risk of leaving the developing country worse off under target and trade because of inadvertent stringency. A target only slightly below BAU would also yield negligible risk of leaving the developing country worse off.

- Emissions targets for developing countries set below their business as usual emission level would result in gains from trade lower than with a BAU target, though providing environmental benefits. The higher costs of a target set below BAU are borne by both the developing countries and the Annex I countries.

There are significant gains from trade for developing countries and large cost-savings to the U.S. if even one large developing country accepts an emissions target at BAU and participates in emissions trading. Table 1 and Charts 1 through 3 illustrate these gains from trade from a baseline of full Annex I trading.

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| Trading Scenario | Permit Price[1] (1997$/ton) | Country Gaining | Gains from Trade with Developing Countries |
|---|---|---|---|
| Annex I only | $54 | United States | not applicable |
| Annex I + China | $26 | China | $3.6 billion/year |
| | | United States | $11.6 billion/year[2] |
| Annex I + India | $47 | India | $1.6 billion/year |
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[1] These scenarios do not account for the cost savings available through the Clean Development Mechanism and carbon sinks.

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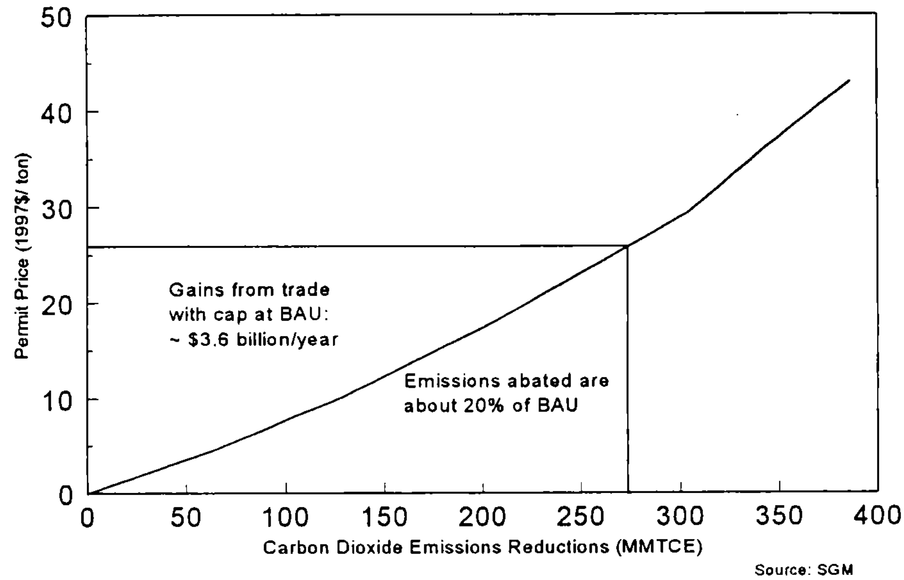


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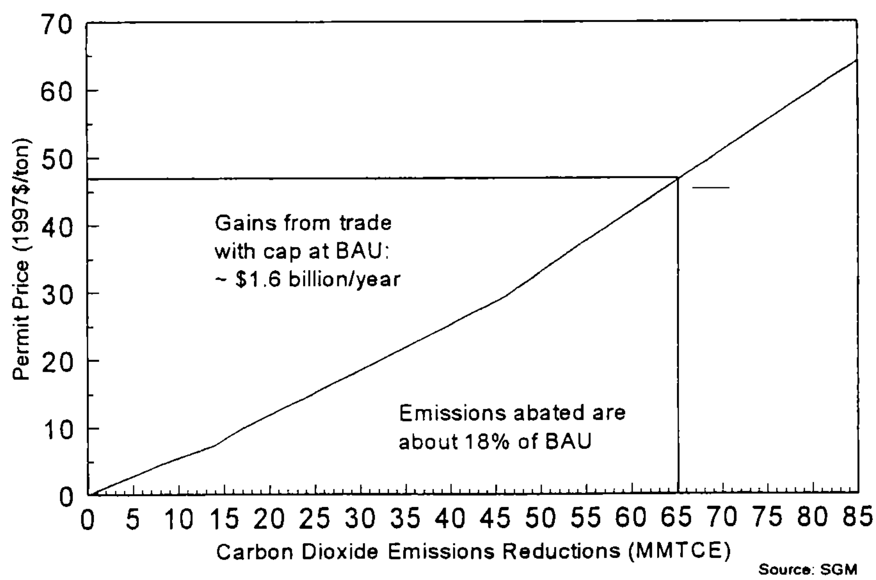

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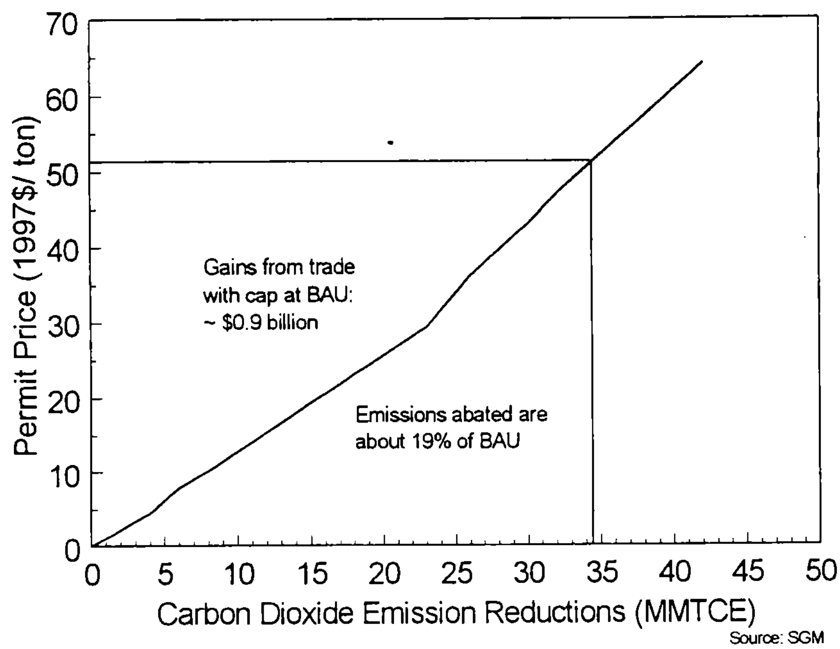


**IV. How Far Below BAU Should the Developing Countries' Targets Be Set?**

The answer to this question has many dimensions. Most commonly discussed is the issue of fairness: what commitments to reduce emissions should be made by countries whose economic resources differ substantially? Generally neglected but discussed below is the issue of efficiency. In particular, what are the implications for U.S. costs of increasingly more stringent targets on emissions from key developing countries?

More stringent developing country targets raise U.S. costs by restricting the supply of permits in world markets and so raising the price of permits. To assess the magnitude of this effect consider the target which just leaves a country no better off than no target at all. This "indifference" target is where the costs of meeting the target just equal the net gains from selling permits in world markets. Chart 4 illustrates gains from trade for a small country. For a target that is equivalent to a reduction from BAU of 17 MMTC, net gains from foreign exports are B, and the cost of meeting the target is C. Since B = C in this example, the net gains from trade are nil.

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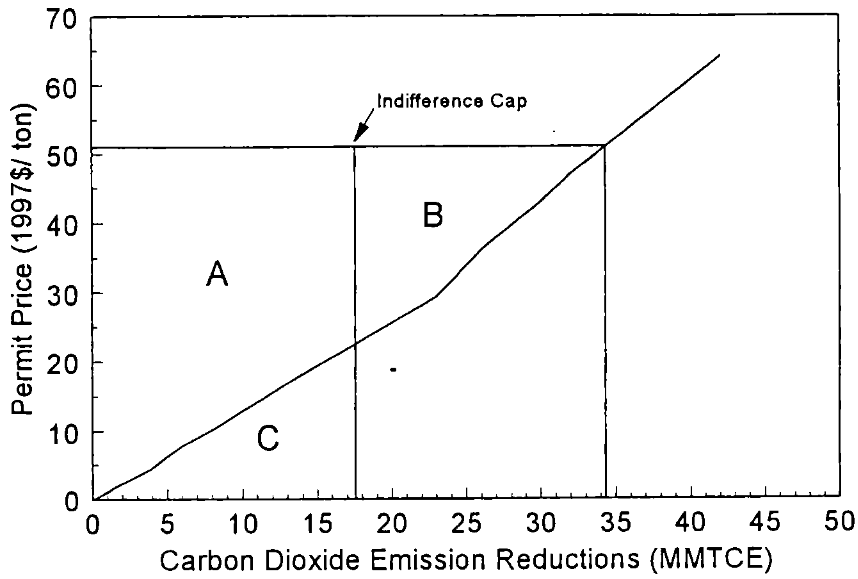


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Table 2. Effects of Various Chinese Emissions Targets with Annex I Trading

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B. Methods

We have estimated a fixed effects linear regression on the logs of these variables, for the countries in our data set, excluding those listed in Annex I. Our regression uses four non-overlapping 5 year intervals for each country. Our forecasts include the country specific constants.

C. Results

The fixed effects regression we estimated is

$$\text{Emissions} = a\ GDP_{t-1} + b\ GDP_{t-2} + c\ \text{Population}_{t-1} + \gamma\ \text{trend}$$

Emissions are the natural logarithm of the five year non-overlapping average of carbon emissions. All independent variables are lagged. $GDP_{t-1}$ is the log of the gross domestic product in the year prior to the first year in the emissions variable, $GDP_{t-2}$ is GDP in the year two years prior to the first year included in the emissions variable, and $\text{population}_{t-1}$ is the country's population in the year prior to first year included in the emissions variable. Trend is one in the first 5 year period, and 2, 3, and 4 respectively in the subsequent 5 year periods. The useable data included 376 cross-section time series observations. The fixed effects regression used 98 degrees of freedom. The R squared was in excess of 0.99.

Table 3. Model I Results

| Variable Name | Coefficient Estimate | Standard Error |
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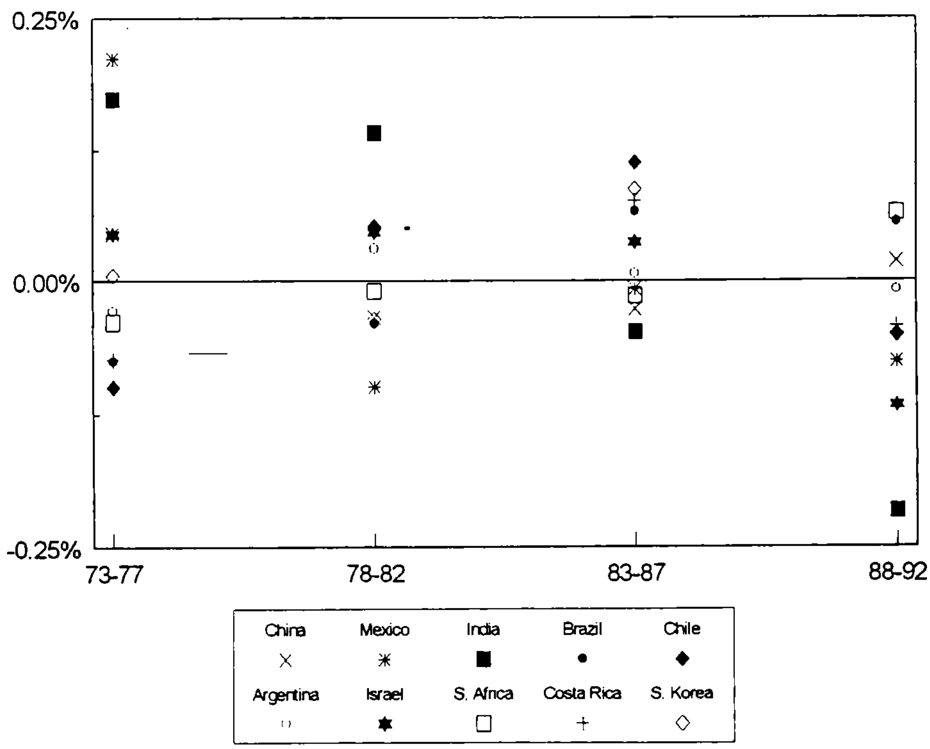
| $GDP_{t-2}$ | -0.411297 | 0.23894 |
| $Population_{t-1}$ | 0.4836006 | 0.2055439 |
| trend | 0.0073712 | 0.0310638 |

As one illustration of the model's accuracy in predicting emissions, consider the chart below that maps actual and predicted emissions using within sample data for ten selected developing countries. The predicted value is never more than 1/4 of one percent away from the actual emissions average for any of the five year intervals.

Chart 5. Error in Model I Prediction as a Fraction of Actual Emissions



To forecast emissions for the five year period beginning in 2008 using the results of this regression we input the World Bank forecasts of GDP for the years 2007 and 2006, and the United Nations forecasts of 2007 population. The forecasts of emissions for the budget period and the confidence intervals around these forecasts conditional on the assumed 2006 and 2007 values are described in the table below.

Table 4. Predicted Average Emissions, 2008-2012

| Country | 2006 GDP (1987$, billions) | 2007 GDP (1987$, billions) | 2007 Population | Predicted Average Emissions, 2008-2012 |
|---|---|---|---|---|
| China | 1,385.8 | 1,493.5 | 1,357,627,000 | 2092 MMTC SE: 1.37 MMTC |
| India | 752.1 | 799.7 | 1,140,563,000 | 345 MMTC SE: 1.34 MMTC |
| Mexico | 268.2 | 282.7 | 113,385,000 | 157 MMTC SE: 1.33 MMTC |

The 95 percent confidence interval around the predicted emissions is approximately ± two standard errors. As shown in figure 1, these developing countries would incur net costs of a target and trade only if the target were about half the reduction needed to raise the marginal cost of abatement to the world price. Given figures 2-4, these levels are about 9 to 10 percent below BAU. Since such reductions from BAU are more than 10 times greater than the standard error, the risk of net costs is negligible, given the model.