APPENDIX 1. DOES REDUCING AIR POLLUTION REALLY LEAD TO IMPROVEMENTS IN HEALTH?

A discussion note and assessment of the evidence on ex post health studies

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1. INTRODUCTION, BACKGROUND, OBJECTIVES

1.1 Evidence linking outdoor air pollution and health

In the past 15 years or so, many hundreds of well-conducted epidemiological studies have been published associating ambient air pollution – notably ambient particulate matter (PM), also ozone and other gases – with adverse changes in health, with greater usage of health services, with earlier mortality, and with other increases in health-related adverse effects such as absenteeism from school.

Principally, these have been time series and panel studies of the more-or-less immediate effects of short-term exposures, where results have shown a remarkable consistency over time and location. Extensive methodological research has shown that these associations are almost certainly not due to residual confounding with climate. Several notable and well-conducted studies of the effects of long-term exposures have also been published. Toxicological studies in recent years have also identified several plausible mechanisms that might explain why the relatively low levels of outdoor air pollution in cities in Europe and North America might give rise to the health effects identified.

Many, probably most, people who have studied the now extensive research literature on air pollution and health think that

- well-conducted epidemiological studies of standard design already provide convincing evidence that higher air pollution is associated with earlier mortality and greater ill-health; and that
- in the context of the evidence as a whole, the best interpretation of that association is that it is causal.

Thus, it is now very widely accepted that these associations reflect a causal relationship between outdoor air pollution and health. By this we mean that increases in the outdoor air pollution (especially particles and ozone) to which communities are exposed will lead to increases in health problems in those communities; and, conversely, reductions in pollution will lead to improvements in health. There remains considerable discussion of, and continuing research into, what pollutants are responsible.

1.2 Some policy implications of that evidence

The increasing evidence linking ambient air pollution and health, and its interpretation as causal relationships, have had many implications for policy. In many countries, standards for outdoor air pollutants have been strengthened, and various strategies have been put in place to reduce emissions and pollution levels.

Increasingly, Health Impact Assessment (HIA) of such policies is carried out. HIA is a methodology which uses the available scientific evidence on air pollution and health, and links it with (i) actual or predicted changes in pollution levels and with (ii) demographic information on the population exposed (including information on background levels of ill-health and of health service usage in those communities), to provide estimates of the impacts on health of planned or actual policies that affect air pollution.

1.3 The search for evidence validating HIA models

Although HIA models are based on evaluations of large numbers of studies world-wide, there remains a scepticism about the reliability of their results.

We do not know exactly what is the basis for this scepticism. It may be in part a residual doubt about the causality of the core relationships linking air pollution and health. It may also be because there are acknowledged uncertainties, sometimes important ones, in any HIA.

Whatever the basis for scepticism, it often shows as a desire to 'see' (or to be shown) the benefits of air pollution reduction, in some definitive way. It is likely that this wish will remain unfilled – studies evaluating the benefits of a policy change are no easier to carry out reliably than the core epidemiological studies on which HIA assessments are based. This is because:

- Air pollution is but one of many factors influencing health, and its role may be small relative to other known and unknown causes;
- Similar issues of confounding (of separating the effects of air pollution from other health-related factors that vary with air pollution) apply as in the core studies.

It follows that, under 'normal' circumstances, it is difficult to identify and attribute reliably the health benefits of small reductions in air pollution.

1.4 Intervention studies do show something genuinely new

There are however occasions where, by design or as the side-effect of other policies or social processes, the change in air pollution is sufficiently dramatic that the benefits to health are (or should be) relatively easily discernible. Increasingly, studies of these situations are being published, with the purpose of establishing whether the anticipated changes in health do indeed occur. Such studies and their results have been the focus of considerable attention in recent years; indeed, ever since the striking results of Clancy et al. (2002) were published. And it is likely that further studies will be carried out in the coming years. For example, in the USA, the Health Effects Institute published a Request For Applications (RFA) inviting proposals for studies of the health effects of interventions that reduce pollution.

Such studies do provide genuinely new evidence about air pollution and health. This can be seen by contrasting their design with the most commonly used designs of standard epidemiological studies. Specifically:

i. ***Time series and panel epidemiological studies*** examine how ***very short-term (daily) variations in air pollution within a community*** are related to changes in health (daily numbers of deaths, hospital admissions, people reporting respiratory symptoms) in the days immediately following the air pollution changes.

ii. ***Cross-sectional, longitudinal and cohort studies*** examine how ***longer-term differences in air pollution concentrations between individuals or communities*** are related to changes in health (age-specific death rates; age-specific prevalence rates of chronic respiratory disease) experienced by those individuals or communities. (Longitudinal and cohort studies examine changes in health within individuals; but the variations in pollution with which these changes in health are compared are pollution changes *between* individuals and communities.)

By contrast,

iii. ***Intervention studies*** examine how ***longer-term changes in air pollution within communities*** are related to changes in health within those same communities in different time-periods.

Thus, intervention studies examine pollution changes that last for months or years (rather than just daily variations in pollution) and they examine the effects of those changes within communities (rather than between them). It may well be this combination of circumstances or design which makes intervention studies attractive as a way of investigating if reducing air pollution leads to benefits to health. By design, there is something direct about these studies that appears to be more convincing than the evidence of standard epidemiological studies.

This is not to say that, by design, intervention studies are free of difficulties. Far from it. The key issue is that other factors that influence health may also have changed over time over the same period as pollution fell. This is a well-known and unavoidable difficulty in using the 'before-after' design implied by an intervention. Its effect can be minimised if:

- the pollution changes are relatively big and relatively rapid;
- they arise from policies which leave no-pollution aspects largely unchanged.

These favourable circumstances are more likely to occur when the pollution changes arise from policies specifically targeted to reduce pollution. They are less likely when the pollution changes are as by-product of other wider, social, changes.

1.5 Aim and methods of the present report

The aim of the present report is to review this emerging series of studies and to assess what they imply for our understanding of air pollution and health generally, and for the reliability of HIA in particular.

In 2003 the World Health Organisation (WHO) published a review of a wide range of issues concerning the health effects of PM, NO_2 and ozone. This was prepared in response to a series of questions from the European Commission as part of its Clean Air For Europe (CAFE) programme. The WHO review included a brief Section summarising the evidence that marked changes in air pollution lead to identifiable benefits to health.

The WHO process involved consultation with and review by a very wide range of well-established experts on issues of air pollution and health. Against the background:

- Of WHO's ability to tap into the knowledge of the research and policy communities;
- That WHO's report was relatively recent; and
- Of the interest in intervention studies within the research and policy communities

We did not carry out a new and fundamental literature search of intervention studies. Rather, we took a lead from the short Sections of the WHO Report, and then carried out a much more in-depth evaluation of those studies than WHO had done or had needed to do.

The present Chapter is the outcome of that process.

2. OVERVIEW OF THE STUDIES

2.1 Air pollution episodes

We begin with a few words about air pollution episodes. These are situations where, by virtue of a combination of emissions, climate (especially temperature inversions) and locations, communities are exposed to unusually high concentrations of air pollution over days or weeks. More than 50 years ago, during the London smog, the effects on health were so clear-cut (greater mortality and ill-health in the days immediately following days of the episodes; reductions in ill-health to 'normal' levels when the pollution subsided also) that there was no great argument about the causality of the relationships, and widespread support for policies (notably, a ban on the burning of coal for domestic heating) which has virtually eliminated them. Air pollution episodes have been well studied; this report does not re-assess that evidence. These remarks are included to show that there have been situations when air pollution changes have been clear enough that effects on health could also be shown clearly.

What seem to be at issue are the claimed effects on health of so-called 'normal' levels of ambient air pollution; i.e. not the extraordinary levels that get called 'episodes'. As noted above, it is no easier to study these than it is to carry out the core epidemiological studies on which HIA assessments are based. Indeed, from one viewpoint, time series studies of daily variations in mortality or hospital admissions relative to daily variations in air pollution *are* validation studies of the effects of (unintended) day-to-day variations in outdoor air pollution. We seek, then, intermediate situations, where changes in air pollution have occurred that are remarkable in relation to daily variations around 'normal' levels; but at the same time, do not constitute air pollution episodes.

2.2 Studies of temporary air pollution changes

One kind of situation is when pollution is clearly or dramatically reduced for a short period of time, and then reverts to its former 'normal' levels in what might be called an 'anti-episode'. In these situations, the pollution changes will almost certainly arise as the unintended side-effect of policies designed to achieve other purposes. In this report we consider two such situations: a temporary (13-month) reduction in particulate air pollution in Utah Valley 1986-87, and the much shorter (17-day) reductions in air pollution in Atlanta, Georgia, because of changes to transport during the Olympic Games of 1996.

As in studies of episodes, these situations allow comparisons of health, pollution and other factors in the low-pollution period with corresponding characteristics both before and again after the air pollution changes.

2.3 Studies of sustained air pollution changes

In other situations, the reductions in air pollution have been sustained. Where the change is gradual, e.g. over many years, it may be impossible to disentangle the effects of the change from those of other co-varying factors which also affect health. Thus, though there have been major improvements in air quality in the UK over the past 50 years, there is no direct evidence (other than the absence of smog episodes, and the core epidemiological studies) of the health benefits of such reductions.

Situations more favourable to assessing the possible benefits are when reductions in pollution are both dramatic and more-or-less immediate. Studies in recent years have reported on two such situations. Separately in Dublin and in Hong Kong, in 1990, specific policy interventions were made to reduce ambient pollution. The policy changes were successful. In this report we consider two studies, one in each location, looking at the impact on death rates. (Other studies in Hong Kong have examined effects on respiratory morbidity also.)

Dramatic and sustained reductions in air pollution also occurred in former East Germany (German Democratic Republic) in the years following German unification, also in 1990. These changes in pollution were sufficiently marked to present a good opportunity of assessing health benefits. Several studies were carried out and have been reported; we consider three of them in this report. A complication in the German experience is that post-unification, communities in East Germany experienced a concurrent process of ‘westernisation’; this complicates interpretation of the associations between air pollution changes and health.

Finally, the California Children’s Health Study (CHS) provided the opportunity to examine a different kind of sustained air pollution change. The study focussed on children in 12 areas of Southern California, with diverse concentrations of ambient air pollution. As one sub-study within the CHS, researchers followed up children who had changed residence from one study area to another. Some experienced higher levels of pollution as a consequence, some experienced pollution reductions. The groups as a whole afforded the opportunity to examine clear changes in ambient pollution relative to health; and we consider also the results of the study that examined lung function changes in those children.

We begin with the studies of sustained air quality changes.

3. STUDIES OF SUSTAINED AIR QUALITY CHANGES

3.1 Coal ban in Dublin

Policy intervention

Clancy *et al.* (2002) describe succinctly a policy intervention in Dublin, as follows: *‘On Sept 1, 1990, the Irish Government banned the marketing, sale and distribution of bituminous coals within the city of Dublin. The effect of this intervention was an immediate and permanent reduction in average monthly particulate concentrations.’*

Study design

Clancy *et al.* assessed the effect of this intervention on death rates in Dublin, by comparing air pollution, weather and deaths by season (Spring, Summer, Autumn and Winter) in two six-year periods – immediately before the ban (1984-90) and immediately after (1990-96).

Effects on ambient pollution

Pollution, as assessed by ambient concentrations of black smoke (BS) and SO_2 from six residential monitoring stations in the city of Dublin, was dramatically different before and after the ban. On average over the 6-year periods, BS fell 35.6µg/m^3 (71%) from 50.2 to 14.6µg/m^3; SO_2 fell by 11.3µg/m^3 (34%) from 33.4 to 22.1µg/m^3. The reductions were statistically significant in each of the four seasons, but were markedly greatest in Winter, then Autumn, Spring, and least in Summer, reflecting the pre-ban use of coal for domestic heating. Average temperature was very similar in both periods; the later period was more humid in all seasons except Summer.

Effects on mortality: methods and results

Statistical analyses used a generalised linear model with assumed Poisson distribution of Dublin death rates – age-standardised, to take account of demographic changes between 1984-90 and 1990-96, including in age-distribution. Analyses adjusted also for influenza epidemics; for temperature, humidity and day-of-the week; and for unmeasured secular trends in death rates (assessed via changes in death rates in the rest of Ireland).

Unadjusted mortality results overall for non-trauma deaths showed a clear and highly statistically significant reduction of 8% between the two 6-year periods, from 9.41 to 8.65 per 1000 person-years at risk. Reductions were found in all four seasons, most strongly in Winter, least strongly in Autumn. Adjustment via Poisson regression analyses lowered the estimated percent reduction to 5.7%; but this nevertheless was very highly significant statistically ($P<0.0001$; 95% CI 4.1-7.2%).

It is interesting and relevant that in cause-specific analyses, the highest adjusted percent reduction was for respiratory causes (15.5%; 95% CI 11.6-19.1%); then cardiovascular (10.3%; 8.0-12.6). (In terms of 'lives saved', the greatest impact was on CV deaths, because many more people are affected than for respiratory causes.) On the other hand deaths from other non-trauma causes showed a slight *increase* (of 1.7%; $p = 0.17$; 95% CI -0.07-4.2%) between 1984-90 and 1990-96. This cause-specific pattern is exactly consistent with what would be expected, based on ambient air pollution generally.

The adjusted percent change was somewhat *higher* in younger people: the estimated adjusted percent reduction from 1984-90 to 1990-96 was 7.9, 6.2 and 4.5 respectively in the three age-groups reported – people aged <60; 60-74; and 75+. The reduction was highly statistically significant in all three age-groups.

Interpretation and conclusion regarding the effect of the intervention

The authors discuss in some detail the adequacy of adjustment for non-pollution confounders. They reported that '*adjustment for respiratory epidemics and weather had a small effect*' on results for total deaths. Changes in underlying demography were substantial, but availability of 5-year census data helped in making reliable adjustments. There were very marked reductions in mortality in Ireland from CV causes over the years of the study, and some reductions in respiratory mortality also. These reductions appear to be traceable to reductions in risk factors. The study took account of these by adjusting death rates in Dublin for those in the rest of Ireland. This was clearly a useful thing to do; but whether or not there remains important residual confounding depends on whether the lifestyle changes underlying the general Irish reductions in CV and respiratory mortality were similar in Dublin and in the rest of Ireland. Dublin being by far the largest city, there may be differences.

Nevertheless, the adjusted results show very clear differences in age-standardised death rates before and after the coal ban in Dublin, and it is difficult to disagree with the authors' main conclusion – that, while non-pollution factors partly explained the overall reduction in non-trauma death rates between 1984-90 and 1990-96, the ban on coal and associated pollution also contributed clearly and identifiably to the reduction.

Other implications for our understanding of air pollution and health
The study gives some insights into other topics relevant to air pollution and health.

a. *Relative importance of various pollutants and sources:* The change was due to reduced BS and SO_2, from reduced coal burning. Much of modern Western urban air pollution is traffic, where as well as primary particles (which will appear as BS) the mixture includes NOx rather than SO_2, with consequent effects on ozone also.

b. *The time-series studies capture only some of pollution-related mortality*: Clancy *et al.* make this point. The estimated adjusted of 5.7% overall, per approximately 35μg/m^3 reduction in BS, is substantially more than the estimate of about 0.5% per 10μg/m^3 PM_{10} from APHEA, and lower estimates from the GAM-adjusted analyses of the US multi-city NMMAPS study. Clearly, the observed reductions cannot be explained by effects captured by these time series; i.e. effects that occur within a week of the relevant daily pollution.

c. *A substantial part of the effect of pollution on mortality occurs within weeks or months; i.e. much of the benefits as assessed via cohort studies are not delayed long-term.* This point is a kind of mirror-image of b., above. By design, the Dublin study picked up on changes in death rates that occurred within six years of the coal ban. It is clear from Clancy *et al.* (Fig 2) that a great part of the reduction happened in the months immediately following the ban. The time-delay from pollution change to full impact on death rates is one of the important unknowns in air pollution mortality – the cohort studies are uninformative about this aspect – and so the evidence from the present study of substantial and sudden benefits is important supplementary evidence.

3.2 Hong Kong

Policy intervention
As described by Hedley *et al.* (2002), *'On July 1, 1990, all power plants and road vehicles in Hong Kong were restricted to use fuel oil with a sulphur content of not more than 0.5% by weight.'*

Study design
Hedley *et al.* (2002) examined cause-specific mortality and pollution in the 5 years after the intervention, taking account of baseline values in the years before the change. Mortality baseline rates were based on the 5 years prior to change; pollution baseline data from five monitoring stations referred to the 2 years before the change, data from a further three stations referred to data for 1 year only. The study examined differences in deaths over 5 years after the change between districts with and without sustained reductions in pollution (SO_2) relative to baseline – sustained being interpreted as the reductions measured as at 2.5y after the change.

Effects on ambient pollution
There was an immediate and marked decrease in ambient SO_2. Baseline levels (data from 5 stations, over 12 months) were 44.2µg/m^3. One year after intervention, they were 20.8µg/m^3, a reduction of 53%. Levels increased slowly over the following years, to 24.5µg/m^3 five years after intervention; a reduction of 44.7% on baseline.

Sulphates within respirable particles showed an initial decrease, of 23% (from 8.9 to 6.9µg/m^3) after 12 months, then rising to 7.9µg/m^3 (reduction of 11.7% on baseline) after 2.5y and returning to 8.9µg/m^3 at 5 years after intervention (Hedley *et al*., Table 1; the text says that in years 3-5 after intervention, sulphate concentrations were 110-114% of baseline). The authors reported that the rise was part of a regional pattern of sulphate pollution in Southern China.

Ozone levels increased throughout the period. There was little change in either NO_2 or in PM_{10}.

Effects on mortality: methods and results
The main analyses compared mortality before and after the intervention, in terms of mortality overall, age-specific and cause-specific; and in terms of seasonal pattern. Excess risk of death was studied by Poisson regression on monthly death rates, with adjustment for time trend, seasonality and climate. In addition, analyses considered *change* in death rates between two groups of Districts – the high (SO_2) reduction area, served by 4 stations with an average SO_2 reduction of 52.8% over 2.5 years; and the low (SO_2) reduction area, with an average increase of 8.7% over 4 other stations.

There were two main findings. One concerned a marked change in seasonal pattern in Yr1 after intervention – a marked reduction in deaths in the cool season. This reduction was found for deaths in all age-groups, and for respiratory and cardiovascular causes, but not for neoplasms and other causes. *'In the second 12 months a striking rebound in cool season deaths occurred, followed by a gradual return during years 3-5 to the seasonal pattern before intervention.'*

Monthly deaths had been increasing on average by 3.5% p.a. during 1985-90, reflecting demographic changes. The 2nd main finding was a clear and sustained reduction in this increase for all causes and all ages over the following five years. The change was greatest for respiratory causes and also for cardiovascular, with a much lesser reduction for lung cancer and for other non-cancer causes. Cancers other than lung cancer increased as before the intervention. The change was most marked in the high SO_2 reduction areas; indeed, the low SO_2 reduction areas showed a higher increase in mortality after the intervention than before. This general reduction in the rate of increase of mortality is also expressed by Hedley *et al.* in terms of life expectancy.

Interpretation and conclusion regarding the effect of the intervention
This study is interesting because it examines mortality and air pollution in the context of little or no changes in ambient PM_{10}. The two pollutants showing changes were sulphates – with a sustained change for about two years – and SO_2, where the reduction was sustained for the full five years post-intervention studied.

Hedley *et al.* find effects on mortality associated with both pollutants. They interpret the marked seasonal changes of Year1 post-intervention as being associated with the initial sulphate reductions, and the sustained mortality changes over the 5-year period as reflecting an effect of the sustained SO_2 reductions. Their discussion considers in some detail whether these associations are causal – we return to this in the following section.

Other implications for our understanding of air pollution and health

There were several other interesting implications.

- There are mortality benefits associated with a reduction in the sulphur content of fuel oil, used in power plants and in traffic. In addition, earlier studies from the Hong Kong group showed benefits in the health of children, in terms of chronic bronchitic symptoms and bronchial hyper-responsiveness. Hedley *et al.* speculate on whether the benefits might be attributable to that other changes to fuel and products of combustion but, in the absence of knowing what these might be, and with pollution changes measured only in SO_2 and sulphates, this seems speculative. It seems more reasonable to assume that if the changes were due to the intervention – and it seems that they were – then they were due to changes in sulphur content.
- It is notable that as in the Dublin study, the changes in mortality have been found in the causes of death that have traditionally been associated with air pollution: the greatest changes being in deaths from respiratory causes, with cardiovascular deaths having a clear but lower RR. However, the public health impacts from CV causes are greater, because of the greater number of people affected.
- The reductions in (the rate of increase of) mortality were sustained, and SO_2 is the only pollutant measured where the reductions in pollution were sustained. Although many studies have found associations between daily SO_2 and various health end-points, the causality of the relationship, and its independence of PM, has remained questionable and questioned. The evidence is reviewed by Hedley *et al.*, who draw attention differences in results and interpretation between the USA and Europe, with results in Europe more favourable to an SO_2 effect.
- If the effect is due to SO_2, is the study showing the accumulated effect of short-term changes, or is there in addition an effect of long-term exposure? The size of the mortality changes found, at 1.1% decrease per reduction of $10 \mu g/m^3$, is not greatly different than that predicted from time series studies – Katsouyanni *et al.* (BMJ, 1997) suggested a change of 0.6% per $10 \mu g/m^3$. There is, however, a question of whether all the earlier deaths from time series studies will show in monthly death rates – unless ‘harvesting’ is extreme, most of them will. With regard to effects of long-term exposure to SO_2, the most recent analyses of the US American Cancer Society (Pope *et al.*, 2002) do show associations but, curiously, these are with mortality from all groups of causes studied, and not just with cardio-respiratory deaths.
- Another long-standing question is whether or not adverse health effects are associated with ambient sulphates; or, equivalently, health benefits associated with sulphate reductions. Again, the issue is unclear; the evidence is not compelling; and opinions vary. The authors link the marked reduction in cool season deaths in Year 1 post-intervention with the reductions in sulphates which were most marked in Year 1 also. It is reasonable that the issue remain open, but the present study does provide intriguing evidence that sulphates may affect mortality.
- The final point is highlighted by Hedley *et al.*: Following the reduction in cool season deaths in Year 1, there was a strong increase again in Year 2. The authors interpret this as evidence that the pool of susceptible people in Year 2 was augmented because of the relatively few deaths in the Year 1 cool season. This seems a reasonable explanation.

3.3 'East' Germany, after unification

Policy intervention

By contrast with the pollution-specific interventions in Dublin and Hong Kong, the situation in Germany arose from a complex set of issues associated with and following from German unification in 1990. The issue is complex because the processes arising from unification led not only to marked changes in pollution, but to other lifestyle and social changes (collectively bracketed as 'westernisation') which also impact on health. Thus, even if associations are found between changes in air pollution and health following German unification, it is by no means obvious that these changes should be attributed to air pollution.

3.3.1 Krämer *et al.* (1999)

Study design and methods

The study included yearly surveys 1991-95 of 7-yr old children in four differently polluted areas in East Germany and surveys in 1991 and 1994 in two areas of West Germany. A questionnaire with six different questions about infectious respiratory diseases and irritations, and seven questions on allergic manifestations and symptoms, were sent to parents; in all, over 19,000 children participated. A wide range of confounding factors was also investigated. Analyses focused on (i) differences between areas in time trends of symptom prevalence and (ii) associations between symptoms and air pollution in the East German areas. Analyses used logistic regression, adjusting for confounding factors.

Effects on ambient pollution

Average SO_2 and TSP in the 2 years prior to survey was determined for each year of survey and each area. Two of the East German areas showed very marked declines in SO_2 1991-95: from 240 to 76µg/m^3 in Leipzig and from 201 to 63µg/m^3 in Halle. Magdeburg and Altmark in East Germany had much lower starting levels of SO_2 (67 and 68µg/m^3 respectively) and showed declines of about 20% over the five years. Starting levels in Duisburg and Borken in West Germany were much lower again, with lower decline. TSP levels were more similar across all areas, with the strongest decline 1991-94 in Halle and Magdeburg (about one half and one third, respectively). The decline in the other two East German areas was somewhat, though not very markedly, more than in the West German areas studied.

Results

Four of the six results for infectious airways diseases showed a steeper increase over time in east than in West Germany. However, none of the allergic diseases and symptoms showed a time trend significantly different between East and West Germany. All the infectious diseases and irritations, other than pneumonia, showed a significant association with SO_2 or TSP whereas in general the allergies and related symptoms did not. Although the study was not powerful for disentangling the effects of SO_2 from TSP, the results were consistent with other evidence, that upper airways disease and irritations were associated with SO_2 whereas lower airways disease (e.g. bronchitis) was more associated with TSP.

Interpretation and Conclusion

As noted above, there are difficulties in separating out the effects of pollution from other factors that might affect the health of people in the former East Germany. However, the analyses adjusted for a wide range of non-pollution confounding factors, measured at the individual level (as in cohort studies). Also, the pattern of effects found – in infectious airways disease rather than in allergic diseases and symptoms – is suggestive of a pollution effect. On the other hand, it is not well-established that increases in ambient SO_2 or ambient PM are clearly associated with increases in airways symptoms and irritancy in children generally. Specifically, we have not attempted to quantify such effects in our work on HIA of ambient air pollution.

All-in-all, this study does seem to support the view that pollution reductions in East Germany post-unification did contribute to the decrease in children's airways disease and irritations.

Other implications for our understanding of air pollution and health

It may be useful, in the light of these findings, to review the evidence linking ambient air pollution, especially SO_2 and PM, with respiratory symptoms in children.

3.3.2 Studies from Wichmann and colleagues in Neuherberg, Germany – Heinrich *et al.,* 1999 and 2002; Frye *et al.,* 2003 and other studies

Study design

This study is based on three cross-sectional surveys (1992-93; 1995-96; 1998-99) of children aged 5-14, in three different areas of former East Germany (German Democratic Republic). First-, third- and sixth-grade school children were studied; those who had not lived locally for >2y prior to survey were excluded.

Heinrich *et al.* (1999) were able to use data from the 1st two series of surveys only. Heinrich created a longitudinal cohort in each area, of children who took part in at least two consecutive surveys. Both papers by Heinrich *et al.* concern respiratory symptoms; for simplicity, we focus mostly on the later paper, based on more data. Frye *et al.* studied 6th-grade children only.

The three areas initially had different levels and sources of air pollution:

- Chemical plants and power plants were the main sources near Bitterfeld, leading to SO_2, PM, NOx and halogenated hydrocarbons;
- At Hettstedt, the main sources were heavy metal-containing dust emissions from smelters, and the domestic burning of high-sulphur brown coal;
- Near Zerbst, the 'control' area, the only major source was domestic burning of brown coal.

Pollution measurements of SO_2 and TSP were summarised as annual means in the 2 years prior to each survey. Size-fractionated PM was measured for 6 months in 1993 and again in 1999 at time of medical surveys, giving number concentrations within specific size fractions.

Heinrich *et al.* used a 2-stage statistical analysis. In the 1st stage, logistic regression methods were used to estimate respiratory symptom prevalences for the nine combinations of area and survey – adjustment being for age, gender, parental education, parental atopy and various measures of indoor air. The logits of these adjusted prevalences were then regressed against air pollution variables. Various sensitivity analyses were carried out.

Frye *et al.* used a similar 2-stage approach. First, logarithmically transformed lung function variables (FEV_1, FVC and ratio) were regressed on various non-pollution factors. Curiously, age is not mentioned as an explanatory variable; it may be that the variations in age were too small to require correction or to allow it to be done reliably. Then, geometric means of adjusted lung function variables were computed for all combinations of sex, area and survey (presumably, 18 values for each of the three variables) and were regressed on air pollution variables.

Effects on ambient pollution
Air pollution declined drastically 1991-98. Annual mean TSP declined from 1991-98 from 79 to 33µg/m^3 in Hettstedt; from 64 to 25µg/m^3 in Bitterfeld; and from 45 to 29µg/m^3 in Zerbst. Corresponding values for SO_2 were even more dramatic: from 84 to 6µg/m^3; from 113 to 9µg/m^3; and from 78 to 8µg/m^3 in the same three locations, respectively (Heinrich *et al.*, 2002). Numbers of particles less than 2.5µm changed little 1993-98. There was a decrease of about 45% 1993-98 in accumulation-mode particles of size 100-500nm; and an *increase* of about 40% in nucleation-mode particles, i.e. 10-30nm.

Pollution-related effects of health
After exclusions, ***Heinrich et al.*** used data from 6959 questionnaire referring to 4949 children. Many changes 1992-3 to 1998-9 were found in non-pollution factors.

Having adjusted for age, sex, parental education and parental atopy, the location-and-survey-specific adjusted prevalences of various respiratory symptoms were associated with annual average pollution levels (PM_{10} or SO_2) in the 2-yr periods prior to surveys. The association was strongest and most significant statistically for 'lifetime' bronchitis. This was expressed as an OR of 3.02 (95%CI 1.72-5.29) per 50µg/m^3 PM_{10} or OR of 2.72 (95%CI 1.74-4.23) per 100µg/m^3 SO_2. Frequent colds (>2 in the previous 12 months) were also statistically significantly elevated (OR 1.9; 95%CI 1.17-3.09 per 50µg/m^3 PM_{10}) and the OR for lifetime sinusitis was just statistically significant with PM_{10} at the 5% level (OR per 50µg/m^3 PM_{10} of 2.58; 95%CI 1.00-6.65). Lifetime otitis media, lifetime shortness of breath, febrile infections (>1 in past 12 months) and cough in the morning (usually, in fall and winter season) all showed pollution-related elevated odds ratios, but not statistically significantly so.

When children were sub-classified according to whether or not they lived in homes with significant indoor exposures, the ORs with outdoor PM_{10} and SO_2 were higher among those without indoor sources of pollution. The results for bronchitis and frequent colds were similar across age groups and birth cohorts.

Frye et al. studied results from 2493 children in sixth-grade across the three areas and surveys. They found increases between 1992-3 and 1998-9 in FEV_1 and FVC separately for boys and girls, with little or no changes in FEV_1/ FVC ratio. Geometric mean adjusted FVC was statistically significantly related to air pollution in the study group overall. For example, a 50µg/m^3 decrease in TSP was associated with a 4.7% increase in adjusted FVC (95%CI 0.2-9.5%), the association being much stronger in girls than in boys. A similar strength of association was found with SO_2. Adjusted FEV_1 was also negatively associated with air pollution, but the results fell far short of statistical significance.

Interpretation and conclusion regarding the effect of the intervention
As noted by Heinrich *et al.*, it is likely that there were concomitant changes 1991-99 in other (unmeasured) factors such as diet and medication use which might affect prevalences of respiratory symptoms. This complicates interpretation of the observed associations as causal. However, the authors do think that their results support a real pollution-related gain in health, and so support a causal role for combustion-related air pollutants.

As for Krämer *et al.* (1999), Heinrich *et al.* found that temporal changes in prevalence of asthma, hay fever and allergic sensitisation were inconsistent and not related to pollution. They concluded that their study does not support the view that long-term exposure to coal combustion particles is related to these endpoints. Alternatively, there may have been pollution-related declines in these endpoints also, but offset by changes in diet etc. and more generally, by 'westernisation' – the increase in asthma in recent years being principally a problem of the industrialised, or post-industrial, Western countries.

Other implications for our understanding of air pollution and health

- Heinrich *et al.* note that their results suggest that particle mass concentrations play a more important role than nucleation-mode particle numbers in respiratory illnesses such as bronchitis, otitis and infections.
- Both sets of authors conclude that the main air pollution influence on the children's respiratory health was the more recent exposure prior to survey, rather than the heavy exposures in early life.

3.4 California, USA

Policy intervention

John Peters and co-workers have been carrying out a study (The Children's Health Study – CHS) of 12 Southern California communities with differing levels and types of air pollution. Results from the CHS, based on children who stayed in the same communities, showed that children living in areas of higher ambient PM_{10}, NO_2 and acids had lower rates of annual lung function growth (Gauderman *et al.*, 2000, Ref 17 of Avol *el al.*).

The present study is based on 110 children in the CHS who moved from one community to another. Thus, the 'policy intervention' was the aggregate of multiple family decisions to re-locate to another area of Southern California.

Study design

Avol *et al.* (2001) examined, for these 110 subjects, relationships between (i) changes in annual average ambient pollution, by virtue of moving area and (ii) changes in annual growth rates of a range of lung function measures: FEV_1, FVC, MMEF (maximal mid-expiratory flow) and PEFR (peak expiratory flow rate).

Effects on ambient pollution

The changes were in the ambient pollution *experienced by the study individuals as a result of re-location,* not in within-community levels of pollutants; change was measured as the difference between 1994 values in the original community and 1998 levels in the 'new' community. Many children experienced increases in air pollution, many other reductions. With regard to ambient PM_{10}, for example, the changes ranged from -50µg/m^3 to about +38µg/m^3, with 90% of the distribution within -30 and +30µg/m^3 (approximate data, taken from Fig 1 of Avol *et al.*).

Results

Avol *et al.* reported that the children who moved and were studied were not noticeably different, in terms of a wide range of baseline health and other factors, from the many more CHS subjects who stayed in the same locations. Within the movers, changes in annual average PM_{10} were negatively associated with annual growth rates in PEFR (p=0.007), MMEF (p=0.04) and FEV_1 (p=0.06); changes in FVC were minimal. Use of annual average

NO_2 or O_3 (10am to 6pm average levels) rather than PM_{10} also showed negative associations between pollutants and annual lung growth, but only that for $FEV_1$and NO_2 approached statistical significance at conventional levels (Avol *et al*, Table 2). These were analyses of the individual-level results. They were supported by analyses at the community level. In addition, there was some evidence – not statistically significant – that the pollution-related changes were less for subjects who had moved within the previous two years, than for those who had moved 3-5 years earlier. Finally, further analyses using the entire CHS dataset showed that in high-PM_{10} communities, those who moved had better lung growth than those who stayed ($p=0.09$), while the converse was true in low-PM_{10} communities.

Interpretation and conclusion regarding the effect of the 'intervention'

The study provides strong evidence that annual growth rates of a range of lung function measures during adolescence are affected by changes in annual average air pollution in the previous years.

Other implications for our understanding of air pollution and health

The magnitude of the estimated changes in FEV_1 was 6.6ml decrease in annual growth, per 10µg/m^3 annual average PM_{10}. While not *per se* likely to be clinically important in adolescents, effects such as these, if sustained over many years in high-pollution areas, would lead to lower levels of FEV_1 which might have noticeable effects on future health prospects (lower lung function being a predictor of various later diseases, and of shorter life expectancy). Avol *et al.* suggest that the effects on lung function are similar to those of *active* (not passive) smoking (averaged across children who smoke various amounts).

If true, this is important. It suggests a need for further research.

It may also be timely to include changes in lung function in HIA of ambient air pollution, especially particles. A stumbling-block has been the lack of valuation studies. It may however be possible to get around this difficulty, by treating lung function changes as changes in the risk of future serious disease and life-shortening, and valuing them on that basis.

4. STUDIES OF TEMPORARY AIR QUALITY CHANGES

4.1 Utah valley, USA

Policy intervention

Utah Valley, in Central Utah, lies near Utah Lake, and between the Waswatch and the Lake Mountains, with a population of about 250,000 people mostly non-smokers (6% smokers). There are three monitoring sites for ambient pollution. Concentrations of SO_2 are very low, as is particulate acidity (<0.5 µg/m^3 H_2SO_4 in 1989/90 – Pope *et al*., 1991). Particulate levels are high, and are at their highest in Winter, partly because of persistent winter temperature inversions: average concentrations of PM_{10} in Jan/Feb 1989 were 118µg/m^3. Ozone levels are high in Summer (e.g. up to 120ppb) but not in Winter. Winter humidity is low.

The nearby Geneva steel mill, built during World War II, is the major local source of ambient particles. Pope *et al.*(1992) reported that *'when in operation, the mill emitted82-92% of the valley's industrial PM_{10},and it was the major source of overall PM_{10} emissions.'*

The 'policy intervention' was unintended and temporary. As described by Pope (1996), *'Due to a labo(u)r dispute and subsequent change in ownership, the mill was shut down for a 13-month period from August 1, 1986 to September 1, 1987, resulting in a substantial reduction in local particulate air pollution levels.'* Thus, the 'policy intervention' was an industrial dispute; but the associated steel mill closure and reductions in ambient pollution gave an opportunity to study changes in health associated with the changes in pollution.

Study design
The possibilities were noticed and followed up by an econometrician, Arden Pope, at the nearby Brigham Young University. This led to a series of epidemiological studies in the late 1980s and early 1990s, with a wide variety of designs and health endpoints. Not all of the studies focus on the period of closure of the steel mill – sometimes, this is discussed almost incidentally within longer time series of daily results.

Nevertheless, the Utah Valley series of studies holds a special place in modern air pollution epidemiology because of the range of endpoints studies, and the unique situation of temporarily reduced pollution levels being studied.

The present summary illustrates the effect of the steel mill closure by drawing on mortality results reported by Pope *et al.* (1992). In terms of overviewing the series, and for more general discussion of explanations other than air pollution and steel mill closure, it draws principally on an overview paper by Pope (1996). More recently, toxicological studies by Ghio and Devlin have provided further useful information about the toxicity of particles emitted from the steel mill.

Effects on ambient pollution
Pope *et al.* (1992) studied daily mortality and PM_{10} pollution in Utah Valley from April 7 1985 until end December 1989, a time-period that included the period of steel mill closure. Average daily PM_{10} throughout the period was 47µg/m^3. Through the 396-day period of closure of the plant, the average daily PM_{10} was 35µg/m^3, clearly lower than the average of 50µg/m^3 in the 1340 other days studied. Because the plant was closed for just over one year, the comparisons are not confounded importantly by the marked seasonal differences in ambient particles.

Results
In the time series as a whole, Poisson regression analyses showed a clear, statistically significant ($P<0.001$) positive relationship between daily PM_{10} and daily mortality, estimated at a 16% increase in the relative risk of mortality per 100µg/m^3 of PM_{10}. This value is high compared with other studies, where estimates from meta-analyses are typically in the order of a 5% increase per 100µg/m^3 PM_{10}.

With regard to the period of closure of the steel mill, *'actual average deaths per day were 3.2% higher during periods when the mill was open than during the period when it was closed'* (Pope *et al.*, 1992). The authors estimated that, based on the Utah Valley time series as a whole, the 15µg/m^3 difference in pollution would be associated with a 2.3% increase in mortality when the mill was open; they considered that the similarity between observed and expected deaths supported the causality of the finding. As noted above, recent estimates from daily time series where the time-lag between daily pollution and mortality is very small (e.g. < 1 week) suggest lower expected values; but this is compensated for by evidence from time series with longer lags, where substantially higher RRs have been found.

A notable characteristic of the Utah series of studies is that multiple endpoints have been examined, in a wide variety of studies; and there is a broad consistence of results. Thus Pope (1996) notes that *'apparent health effects of elevated* PM_{10} *pollution that have been observed in Utah Valley include:1) decreased lung function; 2) increased incidence of respiratory symptoms; 3) increased school absenteeism; 4) increased respiratory hospital admissions and 5) increased mortality, especially respiratory and cardiovascular mortality'*. More recent epidemiological studies in Utah Valley, such as Pope *et al*. (1999) on heart rate variability, while adding to the overall base of information, do not include the period of closure of the steel mill.

There have, however, been several toxicological studies recently based on particulate filters from ambient sampling in Utah Valley in the late 1980s, during times both when the steel mill was open, and when it was shut. For example, Ghio and Devlin (2001) instilled a soluble supernatant from various filter samples into the lungs of healthy subjects, next-day bronchoalveolar lavage showed more inflammation from the material collected from material near the steel mill, and during the years when the mill was running, compared with the year of closure (results summarised by Beckett, 2001). Differences in composition, including in transition metals, appear to explain the results.

Interpretation and conclusion regarding the effect of the intervention

The 'natural' interpretation is that particles from the steel mill have adversely affected the health of Utah Valley residents, over a wide range of respiratory endpoints and cardi-respiratory mortality. Pope (1996) considers that the internal coherence of the Utah Valley studies, the variety of study designs employed, the relatively clear findings of association, and the similarity of those findings to studies in other locations, strongly supports ambient air pollution as a cause of this ill-health; and, within that framework, ambient PM including particles from the steel mill. He examines various concerns or other explanations. At time of writing, in 1996, there was very limited information on biological plausibility. The recent toxicological studies of Utah Valley dusts, and other general advances in the toxicology of particles, have substantially filled that gap. Other socio-economic changes that happened along with the steel mill strike were small, in terms of their impact of the total population studied, and do not explain the results. Likewise, the possibility that the results were an artefact, due to epidemics of respiratory syncytial virus (RSV) in winters when the plant was open (but not in the winter it was closed) is not strongly supported.

It seems reasonable to accept that the Utah Valley series of studies provides good evidence that temporary closure of the steel plant was associated with and caused clear and identifiable improvements in the health of Utah Valley residents, by means of reduced ambient particles.

Other implications for our understanding of air pollution and health

The Utah Valley epidemiological studies are long-standing and well known and their wider implications have been incorporated into air pollution research. The more recent toxicological studies support the view that particle composition and surface properties, and not only particle size, are relevant to toxicity.

4.2 Atlanta, Georgia, USA

Policy intervention
In order to avoid traffic congestion and air quality violations for ozone during the 1996 Summer Olympic Games in Atlanta, major changes in transportation were introduced over a 17-day period from July 19 to August 4, inclusive.

Study design
Using an ecological study design, Friedman *et al.*(2001) compared traffic, air pollution and health over the 17-day Summer Games period with a baseline period comprising the 4 weeks before, and after, the 17-day period. The authors obtained measurements of the number of asthma acute care events, number of non-asthma acute care events, air pollution, climate and vehicular traffic. The pollutants measured were ozone (1-hr peak), PM_{10}, CO, SO_2, and NO_2. Allergen exposure was assessed as total daytime mould counts on weekdays. Measures of asthma acute care events were obtained from four independent data sources.

Effects on ambient pollution
Weekday 1-hour morning peak traffic counts decreased by more than 20% during the Olympic Games; the reduction at weekends was much smaller. The 1-hr peak ozone concentrations in Atlanta were on average 28% lower during the Games than during the baseline period, at 58.6 rather than 81.3ppb. There were also statistically significant reductions of 18% in CO and of 16% in PM_{10} (from 36.7 to 30.8µg/m^3), with a non-significant decrease of 7% in NO_2 and an increase of 22%, but at very low levels, of SO_2. Meteorological variables were similar during the Games and in the baseline period.

Effects on acute asthma events: Results
Differences between the Games and baseline periods in non-asthma acute care events in all four databases were trivially small. Differences in asthma acute care events were substantial, with reductions of 42%, 44%, 11% and 19% in the four databases. Adjusting for other factors, the difference was statistically significant ($p<0.01$) in one of these, and was borderline significant at the $p<0.1$ level in another. (The power of the comparison was limited by the short, 17-day, duration of the intervention period.)

Interpretation and conclusion regarding the effect of the intervention
The authors conclude that air pollution reduction (ozone, CO, PM_{10} and, to a lesser extent, NO_2) during the Games period was the most likely cause (from among those that the study could assess) of the decrease on asthma acute care events in he 17-day Games period. This view is supported by the general epidemiological finding that exacerbations of asthma are associated with daily variations in ozone and ambient PM. The reductions in air pollution arose from a combination of the intervention policy on traffic, and meteorological conditions. The study was however not able to attribute the changes in asthma acute care to any one pollutant in particular, partly because throughout the study period, there was a relatively high correlation, in the region of 0.58 to 0.69, between ambient O_3 and ambient PM_{10}. However, given the relative magnitude of the average changes in both pollutants – 22.7ppb ozone, 6.6µg/m^3 PM_{10} – then a predominant effect of ozone might be expected.

The authors say that other, unmeasured, social changes during the games period may have played a contributory part – the fact of the Summer Olympic Games is likely to have substantial if untracked effects on how people in Atlanta lived during that period. It is reasonable not to over-claim a pollution effect. If however these other changes were determining, it is curious that there are trivial changes only in non-asthma acute events. Indeed, some pollution-related changes in other cardio-respiratory events might have been expected. If however our conjecture is true, that the pollution-related changes reflected an effect of ambient ozone in particular, then substantial pollution-related CV acute care events were not to be expected.

Other implications for our understanding of air pollution and health
Nothing other than the above.

5. CONCLUSIONS

5.1 Does better air quality lead to better health?

Based on the studies considered here, it appears strongly that the answer is 'yes'.

5.2 Are the results of HIA reliable?

This is more difficult, in that many of the studies look at health endpoints (lung function, respiratory symptoms in the general population) which are often not included in HIA. Thus, their validation of HIA models is at best indirect.

However, comparisons are possible where the intervention studies examine mortality. Here, the studies point to changes in health that are *greater* than would be predicted based on HIA using time series studies only and so they support the move, now conventionally done in HIA work, to base estimates of mortality principally on effects of longer-term exposure, as assessed via cohort studies.

5.3 Concluding remarks

Insofar as the intervention studies have been able to provide evidence relevant to the question of whether reductions in air pollution do lead to improvements in health, the evidence they provide gives strong support to the view that yes, there are real benefits. This indirectly supports HIA work to estimate benefits, even if the specifics of various HIA implementations can be assessed at most only partially.

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