

Lung cancer and urban air-pollution in Dublin: a temporal association?

ZKabir^{1,2}, KBennett³, LClancy²,

¹Harvard School of Public Health Division of Public Health Practice 401 Park Drive Landmark Center, 3rd Floor (East) Boston, MA 02215 United States

²Research Institute for Tobacco Free Society Digital Depot Thomas Street Dublin 8

³Department of Pharmacology & Therapeutics Trinity Centre for Health Sciences St. James's Hospital, Dublin 8

Abstract

In 1990, the sale, marketing and distribution of bituminous coal, primarily used for domestic heating, were banned across Dublin. This study exploits the potential of a 'natural experiment' to assess a temporal association between adjusted annual lung cancer death rates and the changing annual mean urban air-pollution concentrations in Dublin from 1981 to 2000. Annual mean 'black smoke' (BS) concentration was used as an indicator variable for the urban air-pollution mixture. Log-linear Poisson regression model (with an offset) was used to estimate adjusted rate ratios of lung cancer death rates between two periods (1981-1990 and 1991-2000) relative to the year 1990. A significant ($p < 0.0001$) two-third decline in BS concentration ($28.2 \mu\text{g}/\text{m}^3$) was seen between the two periods [pre-ban ($46.4 \mu\text{g}/\text{m}^3$) vs. post-ban ($18.2 \mu\text{g}/\text{m}^3$)]. Relative to 1990 (rate ratio=1), a slightly greater decline (2%) in death rates was achieved in the pre-ban period (1981-1990) when mean annual BS concentrations were very high, but a lower decline (1%) was seen in the post-ban period (1991-2000) corresponding to very low mean annual BS concentrations. In other words, a further fall in adjusted rates in lung cancer was achievable both in the pre-ban and the post-ban periods when simultaneously controlling for BS and smoking. A temporal association thus observed between lung cancer death rates and the changing BS concentrations suggests that control of particulate air-pollution could further reduce lung cancer rates, irrespective of smoking patterns.

Introduction

Dublin, experienced 'smog' episodes in the 1970s and the 1980s, with associated excess case fatality rates in hospital admissions.^{1,2} The sale, marketing and distribution of bituminous coal, primarily used for domestic heating, was banned in Dublin in 1990. A recent study in Dublin also indicated a substantial decline in all-cause deaths, respiratory deaths in particular, following the introduction of the Coal Ban in 1990.³

Long-term follow-up studies in the US^{4,5} and Europe^{6,7} showed a consistent association between lung cancer and air pollution. The strength of such associations is not substantial,^{4,7} because of the overwhelming association between lung cancer and active smoking (almost 90%).⁸ However, biological explanations have been provided showing a dose-response relation.^{4,7} These studies employed different air pollutants, as indicator variables for urban air-pollution mixture, depending on the quality and availability of such data. Total suspended particulates in particular are shown to be consistently associated with lung cancer. The present study used 'black smoke' levels as the indicator variable for urban air-pollution mixture, in line with a recent air-pollution study.³

For judging a cause-effect relationship, temporality and cessation of an exposure through a public-health intervention, are two other important criteria.⁹ This study exploits the potential of a 'natural experiment,' because of a public-health intervention in 1990, and thus examines whether a temporal association exists between population-standardised annual lung cancer death rates and the changing annual mean black smoke concentrations in Dublin from 1981 to 2000.

Methods

Sources of data:

Lung cancer incidence data for Dublin were available only from 1994 onwards.¹⁰ Hence, this study used lung cancer mortality data (International Classification of Diseases-9: 162) from the national Central Statistics Office for the periods 1981-2000.

Mean annual 'black smoke' (BS) concentrations available from 1973 onwards for six fixed air pollution monitoring stations across Dublin Borough were obtained from the Dublin Municipal Corporation and the Environmental Protection Agency. The quality and completeness of such data were independently assessed, and such data were used in a recent air-pollution study in Dublin.³ The air-quality data are also broadly representative of Dublin city-level exposures to the study population. The only smoking prevalence data available for the Irish population were at the national level.¹¹ Therefore, the national-level annual smoking prevalence data for each age-group and sex was applied to Dublin populations. Importantly, the quality of such smoking history data has been reviewed recently.¹²

Statistical analysis:

Log-linear Poisson regression modelling (with an offset) was employed to estimate rate ratios of the population-standardised annual lung cancer death rates, using the GENMOD procedure in SAS (version 8.0). A basic model using age, sex, and the calendar year of lung cancer death was developed first. Next, the annual mean BS concentrations, with a one-year lag period, were included into the basic model. A one-year lag-period was used, because of the following reasons:

- Analyses (with different lag-periods) suggested that a one-year lag period between the population-standardised annual lung cancer death rates (adjusted for age and sex) and the mean annual BS concentrations was the best fit model using deviance, as the measure of goodness-of-fit.
- Secondly, when air pollution exerts carcinogenic effect at a 'late' stage of the multi-stage process, more recent exposures are important determinants of risk.¹³
- Thirdly, lung cancer deaths could also be brought forward when associated with increased urban air pollutants, because disorders other than lung cancer could be associated with lung cancer patients, who are also otherwise elderly and immunologically compromised. This phenomenon is termed 'harvesting' in air-pollution epidemiological studies.¹⁴
- Finally, evidence suggests a decline in lung cancer mortality rates within a short period. For example, the reduced lung cancer mortality rates in Britain in the mid-1950s were in part due to the implementation of the 1956 Clean Air Act.¹⁵

In addition to age, sex, mean annual BS concentrations, and the calendar year of lung cancer deaths, the final log-linear Poisson model included the annual age-sex-specific smoking prevalence. In other words, the adjusted rate ratios of lung cancer death rates in this final model were simultaneously controlled for smoking and BS concentrations. An interaction term (BS and smoking prevalence) was included in all the models except for the basic model. All these models were multiplicative risk models. Statistical significance at $p < 0.05$ was assumed. The adjusted rate ratios of lung cancer death rates were relative to 1990 (rate ratio=1), the year when the coal ban was introduced in Dublin.

Results

In total, 3,559 (2,372 males, 1,187 females) and 3,353 (2,060 males, 1,293 females) lung cancer deaths were reported in the pre-ban (1981-1990) and the post-ban (1991-2000) periods in Dublin, respectively. The annual mean distributions of BS concentrations in pre-ban period vs. post-ban period, with inter-quartile ranges are shown in figure I. The findings suggest a significant ($p < 0.0001$) two-third decline in annual BS concentrations ($28.2 \mu\text{g}/\text{m}^3$) between the two periods [pre-ban ($46.4 \mu\text{g}/\text{m}^3$) vs. post-ban ($18.2 \mu\text{g}/\text{m}^3$)]. The distribution of smoking prevalence and the per-capita cigarette consumption in Ireland are shown in figures II and III, respectively. Figure II shows a significant 4% absolute difference in mean annual smoking prevalence between pre-ban (33%) and the post-ban (29%) periods ($p = 0.002$). Compared to 1970 (=100) in figure III, a 14% increase in annual per-capita cigarette consumption was reported in 1980 (114), since then the rates have fallen (99 in 1990 and 93 in 2000).

Table I shows a relatively high lung cancer death rate (rate ratio > 1) in the pre-ban period in the basic model, and also when BS concentrations were accounted for. Not surprisingly, when both BS and smoking prevalence were included into the basic model, the adjusted rates were lower in the pre-ban period (rate ratio < 1). In the post-ban period, 3%, 2% and 1% fall in adjusted rates were seen relative to the year 1990 (RR=1) when no adjustment (basic model), BS concentrations alone, and then both BS and smoking were accounted for, respectively (table I). Such patterns suggest

Table I. Adjusted Rate Ratios of Population-Standardised Lung Cancer Death Rates in Dublin across three Log-Linear Poisson Models between two periods (1981-1990 and 1991-2000)

	Basic Model (Adjusted for age and gender)	Basic Model +Black Smoke (BS)	Basic Model +BS+ Smoking
	RR (95% CI) *	RR (95% CI)	RR (95% CI)
1981-1990	1.06 (0.93, 1.22)	1.01 (0.86, 1.18)	0.98 (0.83, 1.15)
1990	Reference (RR=1)	Reference (RR=1)	Reference (RR=1)
1991-2000	0.97 (0.85, 1.11)	0.98 (0.86, 1.12)	0.99 (0.87, 1.13)
Whole model:	p=0.01	p=0.01	p=0.01
Deviance:	1.40	1.36	1.35

*RR=Rate Ratio; CI=Confidence Interval

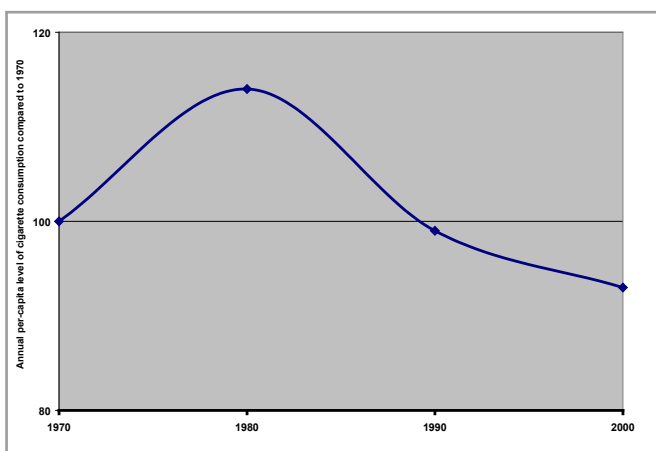


Figure III. Annual per-capita cigarette consumption in Ireland, three year moving average, 1970=100

Source: <http://www.cancer.org/downloads/TOB/Ireland.pdf> (accessed 10th February 2006).

that even when mean annual BS concentrations are very low as seen in the post-ban period, irrespective of smoking adjustment, further reductions in lung cancer death rates are also achievable. Relative to 1990, the basic model also indicates that adjusted rates were 6% higher in the pre-ban period that reduced to 1% when BS concentrations alone were accounted for (table I). So, an overall 5% decline in lung cancer death rates are achievable when mean annual BS concentrations are very high as seen in the pre-ban period.

Discussion

We showed a temporal association between adjusted lung cancer death rates and the changing mean annual BS concentrations in Dublin from 1981 to 2000, irrespective of the smoking patterns. Assuming a cause-effect relationship, a further 5% decline in lung cancer death rates is achievable when mean annual BS concentrations are very high. This reduces to 2% decline in lung cancer rates when smoking prevalence is also accounted for. However, such conservative estimates are in agreement with previous studies.^{5,6,16-18}

We also demonstrated that the 1990 Coal Ban led to a significant two-third reduction in BS concentrations ($28.2 \mu\text{g}/\text{m}^3$). Taken together, this study indicated that the control of particulate air-pollution could further reduce lung cancer death rates in major urban cities, consistent with the British Clean Air Act in the mid-1950s.¹⁵

The poor lung cancer survival,¹⁰ with no significant diagnostic or changing pathologic classifications, is unlikely to influence the observed trend. The overwhelming association between lung cancer risk and active smoking (more than 90%) makes it methodologically difficult to disentangle any small effects due to other competing risk factors.⁸ The Utah steel mill

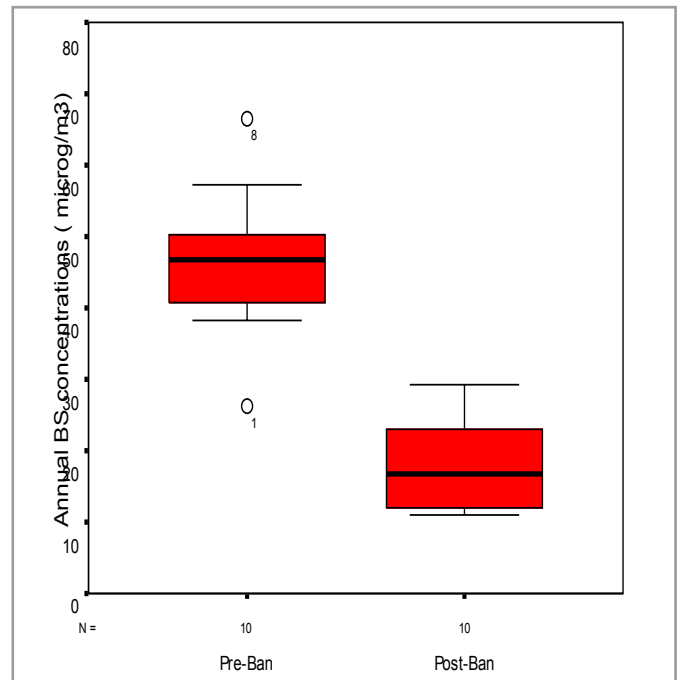


Figure I. Box-and-whisker plot of annual mean Black Smoke (BS) Levels in Dublin between two study periods (pre and post-ban periods), 1981-2000.

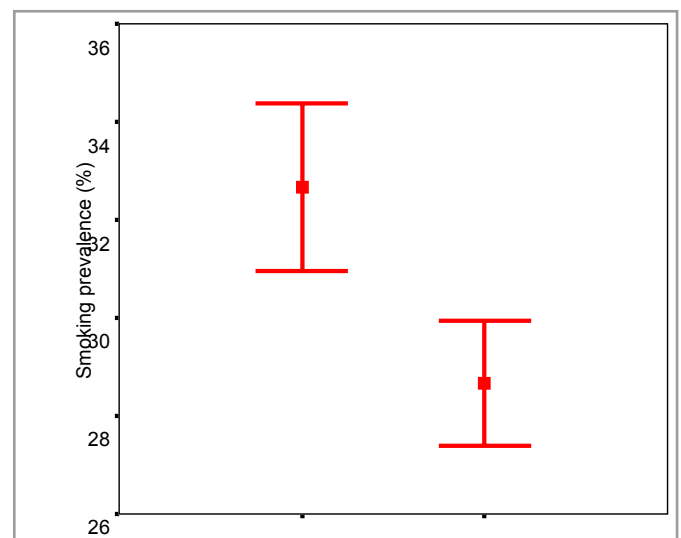


Figure II. Error bar (with 95% confidence interval) showing mean annual smoking prevalence in Ireland between two study periods (pre and post-ban periods).

study in the non-smoking Mormons indicated a 7-10% excess lung cancer death rates when a difference of 30 to 50 $\mu\text{g}/\text{m}^3$ between the exposure levels occurred,¹⁹ consistent with the changing exposure levels in our study. Almost 1% of lung cancers can also develop when exposed to very low air pollution levels.¹⁷ Such low levels closely correspond to the post-ban BS concentrations in Dublin ($18.2 \mu\text{g}/\text{m}^3$).

The Six Cities Study reported a difference in air-pollution levels from 18.2 to 46.5 $\mu\text{g}/\text{m}^3$ between the least polluted and the most polluted cities,⁴ corresponding to the mean annual BS concentrations between our two study periods. The same study⁴ indicated 14 to 20% increase in lung cancer mortality for every 10 $\mu\text{g}/\text{m}^3$ increase. However, a recent prospective study, with a longer follow-up showed a lower estimate of 8%.⁵ Both these studies used fine particles as indicator variables, and if a correction factor of 0.6 (as done in a recent study²⁰) for BS levels is applied to our observed estimate of 5%, the final estimate is also comparable.

The individual estimates reached borderline significance, but our overall model estimates reached statistical significance ($p=0.01$), and fitted well. The observed estimates showed a consistent gradient, and also closely corresponded to previous estimates.^{5,6,16-18} Our models did not include several pollutants, because of lack of data on other pollutants. An auto-correlation between the pollutants is a common methodological issue.²¹ However, the main source of black smoke emissions in Dublin in the 1980s was bituminous coal burning, which accounted for 76% of total smoke emissions in Dublin in the 1980s.¹ Although the cause-effect relationship is unclear, evidence suggests that BS can be an indicator variable for urban air-pollution mixture.²¹ Exposure ascertainment bias is also an inherent methodological issue, consistent with this type of ecologic analysis.²² A multiplicative interactive effect between unknown and/or unmeasured risk factors for lung cancer is a possibility.²³ However, between-city heterogeneity in exposure assessment was greatly minimised in this study design for restricting our analyses only to those populations who were at risk (males and females combined) in a single geographically defined population, namely Dublin.

In conclusion, this study showed an increased lung cancer death rate in pre-ban period relative to the post-ban period, suggesting that control of particulate air-pollution could further reduce lung cancer rates. Better epidemiological study designs using a 'control' area could however establish an underlying cause-effect relationship. For such study designs, historical comprehensive area-specific air-pollutant data are also necessary. Nonetheless, this study shows a temporal association between changing black smoke concentrations and lung cancer death rates, as well as confirms the potential utility of a successful public-health intervention.

Correspondence: Zubair Kabir
Harvard School of Public Health Division of Public Health Practice 401
Park Drive, Landmark Center, 3rd Floor (East) Boston, MA 02215
Phone: +1-617-998-8806
Fax: +1-617-495-8543
Email: zkabir@hsph.harvard.edu

Acknowledgements

The Royal City of Dublin Hospital (RCDH) Research Trust funded this project. We thank Dr Pat Goodman for technical assistance. Dr Zubair Kabir is currently on a joint cancer research fellowship to the Harvard School of Public Health funded through a research grant from the National Cancer Institute (US) and the Health Research Board (Ireland).

Pre-Ban	Post-Ban
---------	----------

References

1. Walsh J, Mollan C, eds. In: Air pollution in Ireland: Dublin: A case study. Dublin: Royal Dublin Society, 1988.
2. Kelly I, Clancy L. Mortality in a general hospital and urban air pollution. *Ir Med J* 1984; 77: 322-324.
3. Clancy L, Goodman P, Sinclair H, Dockery DW. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet* 2002; 360: 1210-1214.
4. Dockery DW, Pope CA III, Xu X, et al. An association between air pollution and mortality in six US cities. *N Engl J Med* 1993; 329: 1753-1759.
5. Pope CA III, Burnett RT, Thun MJ, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA* 2002; 287: 1132-1141.
6. Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet* 2002; 360: 1203-1209.
7. Nafstad P, Haheim LL, Oftedal B, et al. Lung cancer and air pollution: a 27 year follow up of 16209 Norwegian men. *Thorax* 2003; 58: 1071-1076.
8. Stewart BW, Kleihues P. *World Cancer Report*. Lyon: IARC, 2003.
9. Hill AB. The environment and disease: association or causation? *Proc R Soc Med* 1965; 58:295-300.
10. National Cancer Registry Board. *Cancer in Ireland, 1994-2002: Incidence, Mortality, Treatment and Survival*. Cork: National Cancer Registry Board, 2003.
11. Forey B, Hamling J, Lee P, Wald N. In: *International Smoking Statistics: a collection of historical data from 30 economically developed countries (2nd Ed)*. London: Oxford University Press, 2002.
12. Lawlor DA. A book and website all IJE readers should know about. *Int J Epidemiol* 2004; 33: 433-434.
13. Shy CM. Air pollution. In: Schottenfeld D, Fraumani JF Jr, eds. *Cancer epidemiology and prevention*. Second Edition. New York: Oxford University Press, 1996; 406-417.
14. Schwartz J. Harvesting and long term exposure effects in the relation between air pollution and mortality. *Am J Epidemiol* 2000; 151: 440-448.
15. Stevens RG, Moolgavkar SH. A cohort analysis of lung cancer and smoking in British males. *Am J Epidemiol* 1984; 119: 624-641.
16. Karch NJ, Schneiderman MA. Explaining the urban factor in lung cancer mortality. A report of the Natural Resources Defense Council. Washington, DC: Clement Associates Inc., 1981.
17. Doll R, Peto R. The causes of cancer: quantitative estimates of avoidable risks of cancer in the United States today. *J Natl Cancer Inst* 1981; 66: 1191-1308.
18. Cederlof R, Doll R, Fowler B, et al. Air pollution and cancer: risk assessment of methodology and epidemiological evidence (report of a task group). *Environ Health Perspect* 1978; 22: 1-12.
19. Archer VE. Air pollution and fatal lung disease in three Utah counties. *Arch Environ Health* 1990; 45: 325-334.
20. Lacasana M, Esplugues A, Ballester F. Exposure to ambient air pollution and prenatal and early childhood health effects. *Eur J Epidemiol* 2005; 20: 183-199.
21. Beeson WL, Abbey DE, Knutsen SF. Long-term concentrations of ambient air pollutants and incident lung cancer in California adults: results from the AHSMOG study. *Environ Health Perspect* 1998; 106: 813-823.
22. Rothman KJ, Greenland S, eds. *Modern Epidemiology*. Philadelphia: Lippincott-Raven Publishers, 1998.
23. Walker AM. Proportion of disease attributable to the combined effect of two factors. *Int J Epidemiol* 1981; 10: 81-85.