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Particulate Air Pollution and Mortality in Dublin

1980-1996

Submitted for the Award of PhD.

to the University of Dublin



April 1999

Patrick Gerard Goodman BSc. MSc.

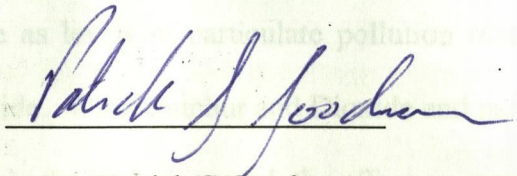
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This work was carried out by myself in the Dublin Institute of Technology, and in the "CREST" Directorate in St James`s Hospital Dublin under the supervision of Dr Luke Clancy.

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Patrick G Goodman

SUMMARY

Air pollution in Dublin was studied for the period from 1980 to 1996. The factors which contribute to air pollution were investigated, and the nature of particulate air pollution is discussed. The trends in air pollution, and the Government interventions in relation to fuel usage, and air quality were evaluated. All non-accidental mortality for residents of Dublin County Borough was studied for the same period. The study covers 16.75 years, or 6119 days. A total of 80,307 deaths used in the study. Giving an average of 13.2 deaths per day.

The data was analysed using robust Poisson regression analysis, while controlling for potential confounders such as temperature, day of the week and humidity. Total mortality was seen to rise as levels of particulate pollution rose, similar effects were observed for Sulphur Dioxide. When Sulphur and Dioxide and particulate pollution were considered simultaneously in the analysis model, the effect on mortality was attributed to particulate pollution exposure. Particulate pollution was seen to have a positive association for all exposure lags investigated. A 5 day moving average of particulate pollution was found to have the strongest short term effect on mortality. This positive by 0.6% +/- 0.1, ($t = 5.8$), for each $10\mu gm^{-3}$ increase in 5 day average pollution level. When age groups were considered, the estimated increase in mortality was highest in the 75 and over age group, giving a 0.93%+/- 0.14 , ($t = 6.6$), for each $10\mu gm^{-3}$ increase in 5 day average pollution level. Stronger effects were observed for cardiovascular mortality and for respiratory mortality, with the most pronounced effect for respiratory mortality in the elderly, with a 1.92% +/-0.3, ($t = 6.5$), rise in mortality for each $10\mu gm^{-3}$ increase in 5 day average pollution level. These results are similar to other published studies.

The Government intervention, banning the marketing, sale and distribution of coal in the greater Dublin area was evaluated. Particulate pollution levels were seen to fall by 67%, when the periods before and after the ban were compared. This indicates that coal burning was a major contributor to particulate pollution in Dublin. When the effect of the coal ban on mortality was analysed, total mortality (for the age 30 and over age group) was seen to fall by 3.1% +/- 1.2, ($t = 2.4$). The biggest fall in mortality was observed for respiratory mortality in the age 75 and over age group, falling by 21.6% +/- 4.4, ($t = 4.9$).

This work also found evidence for a significant effect due to accumulative pollution exposure, this medium term effect was found to be of the order of 45 days. Increases in mortality were found to be strongly associated with accumulative particulate pollution of the order of 45 days. Total mortality was seen to increase by 2.6% +/- 0.15, ($t = 16.7$), for an increase of $10\mu gm^{-3}$ in 45 day average pollution exposure. Respiratory mortality showed an increase of 7.9% +/- 0.23, ($t = 22.5$), for the same increase in pollutant. There was very little change in the estimated effect if the exposure period was extended beyond 45 days.

In conclusion, this work has shown that mortality in Dublin was linked to particulate pollution levels, the oldest age group and those dying from respiratory disease showed the strongest correlation. The coal ban significantly reduced pollution levels, and in turn mortality levels fell, particularly respiratory mortality. This work has also shown evidence for the existence of a significant medium term accumulative exposure component of the order of 45 days. This medium term accumulative expose could be very important in areas which experience strong seasonal pollution episodes.

Dedicated to my wife Colette and my two sons James and David

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1980-1996

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Particulate air Pollution and Mortality in Dublin 1980-1996

INTRODUCTION AND STRUCTURE OF THESIS

INTRODUCTION

This is a detailed study of particulate pollution levels in Dublin, Ireland from 1980 to 1996, and the links of such particulate pollution to mortality within the population. In particular this study tests the hypothesis that there is evidence for a causal link between airborne particulate pollution levels and mortality, and more specifically for respiratory mortality. While conducting this study the lag structure of any such link between exposure to airborne particulate pollution and mortality will also be investigated. This study investigates if there is any evidence of a health benefit from the introduction of the coal ban in Dublin.

STRUCTURE OF THESIS

This thesis is structured to bring the reader progressively through the subject of air pollution and health effects. Chapter 1 gives an overview of published research which indicated that there is evidence for a causal link between airborne pollution and adverse health effects.

Chapter 2 discusses the nature of particulate air pollution, the properties, sources and sinks of such atmospheric pollutants, together with

measurement techniques for measuring ambient concentrations. This theme is continued in Chapter 3 which discusses items which are specifically relevant to the Irish situation as regards the formation of particulate pollution.

Since this work is concerned with the potential adverse health effects of airborne pollution, it is important that the mechanism by which pollution can enter the body are discussed. Chapter 4 gives an overview of the anatomy of the human respiratory system, the respiratory system is chosen as that is the interface by which air enters the body, any pollution present in the air is likely to first interact with the respiratory system. The evidence for the deposition and retention of particles within the respiratory system is also investigated.

Chapter 5 looks at the history of measurement of particulate pollution in Dublin, and also looks at the trends in pollution levels. The exposure data, as used in this study, is discussed in detail, summary tables on this data are also presented. The meteorological data used for this study is also discussed in Chapter 5.

The health effects data, or more specifically the mortality data is outlined in Chapter 6. The source of the data is explained, the selection criteria applied to the data is covered, the sub groups into which the data was divided are also explained, and summary information on the mortality data is also provided. Population changes for the area under consideration

are also discussed, as well as how these changes will be incorporated into the analysis.

Chapter 7 covers the methodology used in this, and other studies, to analyse data of the type available in this study. The suitability of the methodology for use in this study is discussed. The full development of the analysis model as outlined in the methodology is explained in a step by step approach in Chapter 8, with all of the potential confounders being dealt with one at a time, until the final analysis model is complete.

Chapter 9 is a detailed presentation of all of the data analysis, with summary tables of all of the analysis outputs from the model. The lag structure of exposure to pollutant and any adverse health effects is investigated. The effects of particulate exposure on different age groups, and on different categories of mortality, namely *Cardiovascular, Respiratory* and total mortality is also studied. The effectiveness of the ban on the burning of bituminous coal is also investigated. The complete outputs, which are quite extensive in size, are presented in the appendices for cross checking if required. A short comment on the results presented within each table is also provided.

Chapter 10 is a detailed discussion of all of the work presented in this thesis. The background to the study, other work of a similar nature, the methodologies used and all the results discussed in detail. The results are compared with those of other published studies. The novel results from this

work are highlighted and presented. Some hypothesis are presented as to future research in this area.

Chapter 11 comprises of a brief description of the conclusions arrived at as a result of this study on particulate air pollution and mortality in Dublin.

Chapter 1

AIR POLLUTION AND ADVERSE HEALTH EFFECTS

1.1 INTRODUCTION

This chapter outlines some of the published evidence for the belief that there is a link between airborne pollution and adverse health effects. The evidence is reviewed, the most likely pollutants from the literature are identified, the most susceptible population sub groups are identified, and the existence of a safe threshold level is also reviewed.

1.2 AIR POLLUTION

Air pollution in its various forms has been considered bad for human health for centuries. Brimblecombe [1] gives a very well researched history on the reports of adverse health effects due to air pollution, ranging from the time of the Roman Empire, right up to the present century. He even includes a discussion on pollution problems experienced by the early Stone Age hut dwellers.

Here in Ireland, there are also early references to air pollution in Dublin city, with two proclamations on air pollution from June 1634 and July 1665, referred to by Swift [2]. He also reported that Doctors advised on the removal of patients to the suburbs away from the problems of the city. Petty [3] in 1667 had gathered coal consumption figures for Dublin, an indication that coal consumption even then, was linked to air pollution.

There has been considerable interest in the study of air pollution levels in Dublin throughout the course of this century, and these are discussed in Chapter 5.

Kelly and Clancy [4] linked an increase in hospital case fatality rates to a severe air pollution episode in Dublin the early 1980`s. With the advances in computers over the past few years, it is now possible to conduct detailed statistical studies on the links between air pollution and adverse health effects. This current study will investigate the links, if any, between particulate pollution levels in Dublin and mortality, and will cover the period from April 1980 to December 1996, thus including the 1982 episode studied by Kelly and Clancy.

Air pollution can take two main forms, particulates and gases. This study will concentrate on the possible links of particulate pollution with mortality, this is because the author is of the opinion that particulates are the most important type of air pollutant in the Irish context, and wishes to investigate this hypothesis. Furthermore the only gaseous pollutant for which reliable information is available over the study period is Sulphur Dioxide (SO_2); its association with mortality will also be investigated.

1.3 AIR POLLUTION AND HEALTH

Since the middle of this century, scientific studies have linked air pollution with adverse health effects. The most well documented cases are those of the Meuse valley, Belgium in 1930 [5], Donora in Pennsylvania in

1948 [6], and in London England in 1952 [7]. More recently, studies by Schwartz [8], and by Hoek [9] support the view that there is a strong association between ambient levels of air pollution and adverse health effects. The World Health Organisation (WHO) [10], the United States Environmental Protection Agency (US EPA) [11,12,13], and the European Community [14] (or European Union, EU) have introduced action levels which specify the maximum levels of air pollution, which if exceeded require various actions to be taken. This clearly supports the hypothesis of a direct link between increases in ambient levels of air pollution and adverse health effects.

Dublin suffered from a series of episodes of high levels of air pollution during the 1980`s. In response to these high pollution levels the Government introduced the Air Pollution Act 1987 [15], this act became law in 1990. This act banned the Marketing, Sale and Distribution of bituminous coal in the greater Dublin area; the effectiveness of this legislation will be evaluated within this study. A similar ban has now been introduced to cover Cork [16], the second largest city in Ireland; this became effective from September 1995. In 1998 the ban on the use of bituminous coal was extended to cover a number of other large urban areas [17], the extension of this ban had already been recommended [18].

1.4 PARTICULATE POLLUTION

A significant number of recent publications, Mazumdar et al. [19], Schwartz and Marcus [20], Fairley [21], Katsouyanni et al. [22], Kinney and Ozkaynak [23], Schwartz and Dockery [24,25], Pope et al. [26], and Dockery et al.

[27], have all reported increases in daily mortality associated with increases in daily levels of particulate air pollution. All of these studies have reported that the principle correlation between airborne pollution and daily mortality is with particulates and not with Sulphur Dioxide (SO_2). Other studies have however reported evidence of an association between SO_2 and adverse health effects [28,29], while the role of SO_2 has also been reviewed [30].

The data analysed in this study will show that SO_2 levels were relatively low throughout all of the period being considered (1980-1996). It will also be seen that it was the levels of particulate pollution which showed the most variation, and which reached extremely high values during the period under consideration. In this work where reference is made to levels of air pollution, this refers to airborne particulate pollution unless otherwise specified. Where the terms "smoke" or "particulate pollution" are used they refer to particulate pollution measurements unless otherwise stated.

1.5 MORBIDITY AND MORTALITY

As has already been discussed there is substantial evidence which shows that there is a direct link between increased levels of air pollution and increases in daily mortality, [4-7, 19-26] but there is also plenty of evidence which shows that increases in hospital admissions are also associated with increases in ambient air pollution levels, Braum-Fahrlander et al. [31], Brunekreef [32], Hoek and Brunekreef 1993 [33,34], all have show that the pulmonary function of children can be effected by increases in ambient air pollution levels.

For the purposes of this study, the data is incomplete in respect of hospital admissions over the period under investigation; therefore, it is not possible to study the relationship between morbidity and air pollution levels for Dublin. The reason that the morbidity data is incomplete is that complete hospital admission records just do not exist for Dublin for the period of time under investigation. This is due in part to the closure of a number of hospitals during the period, and the amalgamation of others at the same period. Due to these amalgamations and closures, records were lost. The morbidity data that is available is viewed as being insufficient for the purposes of conducting a rigorous statistical analysis of any possible causal links between air pollution and morbidity for Dublin. This study investigates the link between air pollution levels and mortality for Dublin, as comprehensive and reliable daily data is available for both air pollution levels and mortality for the whole period of time under investigation in this study.

1.6 RECENT DEVELOPMENTS IN AIR POLLUTION STUDIES

The studies referred to above, and particularly the work of the Harvard group containing Dockery and Schwartz spawned renewed interest in the study of the health effects of particulate pollution. The six city study in the United States of America (US) [35] certainly highlighted the whole area of particulate pollution and health. In the United Kingdom (UK) a whole series of reports were commissioned by the government who set up expert panels to advise them on air quality and health [30, 36, 37, 38]. In the European

Union a study was approved to investigate the links between pollutant exposure and increases in hospital admissions and in mortality, over a number of European cities, the results of these studies were published in 1996 [39]. All of these studies have reported consistent results that, increases in ambient particulate pollution levels appear to be linked to increases in hospital admissions and mortality, and specifically for hospital admissions and mortality from respiratory disease, and for the elderly age groups.

Pope et al [40] in a review of the evidence on the links between exposure to particulate air pollution and adverse health effects report that "studies have shown adverse acute health effects at pollution levels common in many U.S. cities, including levels well below current U.S. National Ambient Air Quality Standards". What is also alarming is that other studies [24, 41, 42, 43] have found no evidence for a threshold at which particulate pollution starts to take effect. Taken together this could be rather worrying, in that current research is saying that there is no safe level of particulate pollution, and that adverse health effects can be observed at low ambient levels of pollution. In reviewing the evidence of this recent research, Pope et al [40], the UK expert panel [38] and the U.S. state of the art review [44] have all stated that the observed effects from particulate pollution are likely to be real and not due to some artefact of the analysis. It can be stated that there is general consensus within the scientific community that adverse health effects can be observed at ambient levels of particulate pollution, and that there is a causal link between the particle levels and the adverse health effects. This is not a view held by all, some researchers [45] are of a different

opinion on the relationships, while there is also controversy concerning the interpretation of some of the results and the methods of analysis [46, 47].

There is also consensus that those already with an existing respiratory complaint, and the elderly, are most at risk form air pollution [48, 49, 50], this is also supported by the results of studies already conducted [19, 26, 42].

1.7 SUMMARY

As already outlined above there is a body of evidence linking adverse health effects to airborne pollution, and specifically to particulate pollution, this study will investigate if there is evidence for acute health effects from air pollution in Dublin. It will look at possible effects from both particulate pollution and from SO_2 concentrations. If effects are observed the lag structure involved will be investigated, the existence of a threshold or otherwise will be investigated, and the effectiveness of the ban on coal will be evaluated, in relation to air quality, and health effects. The relationship between pollution levels and effects on various sub groups by age, and cause of death, will also be investigated. These investigations will be conducted using the methods and techniques as outlined in Chapter 7. Potential confounders will be controlled for in the final analysis.

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Chapter 2

AIRBORNE PARTICULATE MATTER

2.1 INTRODUCTION

This chapter defines the nature of airborne particulate matter. It discusses the sources and sinks of particulate matter, and the classification of particulate matter by size. The physical properties of the particulate matter are then discussed, and finally the methods of measurement of ambient particulate matter as used in this study are explained.

2.2 AIRBORNE PARTICLES

Particles, which are suspended in the air, may be solid or liquid, and can vary in size from a few nanometers (a couple of molecules), to tens of micrometers (about the size of a grain of sand). These particles are often referred to as being *ultrafine;* (which is particles from approximately .005μm to 0.1μm), *fine* (from 0.1μm to 2μm) and *coarse* >2μm. These definitions can vary slightly from author to author.

In reality, most of the particles are of irregular shape. The most commonly used dimension to specify a particle's size is the aerodynamic diameter, defined as the diameter of a sphere of unit density which has the same terminal falling velocity in air as the particle under consideration. Effectively this means that the particle under consideration behaves or moves in an airflow like a spherical particle with a diameter equal to the

aerodynamic diameter of this particle. This therefore allows one to evaluate how such a particle will behave when it flows in air.

The aerodynamic diameter D_a given by the following equation; (from Finlayson-Pitts and Pitts)[1]

$$D_a = D_g k (\rho_p / \rho_o)^{1/2} \qquad \textbf{(eqt 2.1)}$$

D_g is the geometric diameter

ρ_p is the particle density

ρ_o is the ref. density, taken as 1

and k is the shape factor.

This aerodynamic diameter is useful in that it can help determine the residence time of the particle in air. It can help identify whether a particle is likely to be deposited in the respiratory system or not, and it also provides the basis of operation of a large number of measuring instruments used in particle measurements.

Furthermore, the size of a particle is strongly related to the source from which the particle arises, which in turn is reflected by the residence time the particle will have in the atmosphere.

2.3 SOURCES AND SINKS OF AIRBORNE PARTICLES

2.3.1 Sources

Sources of airborne particles can be loosely classified into two categories *natural* and *anthropogenic*.

Natural

Natural sources of particles can give rise to the suspension of particles into the air. In dry areas, or in the summer time, in the Irish context, dusts from soil, wear and tear on pavements and road surfaces, and tyre debris can all form part of this suspended particulate matter. Strong winds or turbulence from passing vehicles are needed to cause a suspension of these particles.

The breaking of waves on the seashore causes the suspension of tiny droplets of sea water into the atmosphere. Over the passage of time, the water in these droplets evaporates to leave small salt particles, most of which tend to be coarse. However in some instances finer particles are found, evidenced by the fact that some such particles can be detected inland, well away from the sea, although most are detected in coastal areas.

Volcanoes are another major natural source of airborne particulate matter, but are not of major significance in the Irish context. Naturally, occurring forest fires are a major contributor to airborne particulates on a global scale.

Anthropogenic

Human activity quite often leads to the production of airborne particles, and in particular combustion processes are by far the largest contributor to airborne particulates in urban areas. This combustion can be from industrial processes, motor vehicle engines and space heating. Other human activity such as mining, construction work and quarrying can also give rise to particulate pollution. In fact a recent report [2] mentions that exceptional behaviour in patterns of airborne particulate levels was observed at a monitoring site in Cardiff, when construction activity was taking place adjacent to the monitoring site.

In the Irish situation, the Warren Springs report [3] states that the use of smoky coal in domestic fires for space heating was the major source of airborne particulate pollution. An anecdotal case is discussed by Scott [4] which shows how an unusual event, namely the Pope's visit to Dublin, showed a dramatic change in the pattern of particulate pollution. This was associated with the unusual change in human activity and routine at the time of the Papal visit.

2.3.2 Particle Sinks

Particles can be removed from the atmosphere by processes such as coagulation, impaction, washout and sedimentation.

(i) Coagulation

Small particles moving by Brownian motion collide with other particles, and some of these collisions result in the coagulation of particles to form larger particles. In the absence of a renewing source, the number of small particles (ultrafine) decreases significantly with the passage of time, by this mechanism. Coagulation is highly dependent on the size and number of particles present.

(ii) Sedimentation

Solid and liquid particles are more dense than the air surrounding them, and all of these particles tend to fall to the earth under the influence of gravity. This gravitational settling is opposed by the viscous forces present in the air, and by the turbulent motion of the air near the ground. For the larger heavier particles, the typical upward forces experienced are insufficient to overcome the gravitational force, and the particles soon fall out.

(iii) Impaction

When a stream of air carrying a particle flows around an object, a process called *impaction* can occur. This is where the inertia of the particle prevents it from following the airflow, and the particle impacts onto the

surface of the object. Impaction becomes more likely as the particle size and the air speed increase.

This process of impaction is frequently used in measuring instruments, and in filtering to allow through only particles within a certain size range. These three processes discussed above, are collectively known as dry deposition, and are occurring to particles in the atmosphere all of the time.

(iv) Wet Deposition

Wet deposition as the name suggests involves the effect of water vapour on the deposition of particles. Raindrops are quite efficient at scavenging particles from the air. However rainfall is not a continuous process and so its effects are intermittent. The capture rate for wet deposition is lowest for particles in the size range .05μm to 2μm [2].

2.4 PROPERTIES OF AIRBORNE PARTICULATE MATTER

The aerodynamic size of a particle plays a significant role in the way in which the particle behaves in the atmosphere, and in its interactions with the human body.

2.4.1 Ultrafine particles

These very small particles are formed from the condensation of small numbers of involatile molecules. In particular they may be formed in combustion processes. These particles can exist in extremely high

concentrations up to 10^6 particles cm^{-3} (Traditionally particle concentrations have been presented as the number of particles per cm^3, a concentration of 10^6 particles per cm^3, would equate to 10^{12} per m^3, the traditional units will be used in this work). Due to the movement of these particles as outlined in section 2.3.2 they can combine with one another to produce particles in the size range .05μm to 2μm, this is called the accumulation mode.

2.4.2 Fine particles

These particles are often formed from the coagulation of smaller particles. They have long residence times in the atmosphere. They have strong effects in the scattering of light and they can represent a significant element of the mass of particulate matter present in the atmosphere.

2.4.3 Coarse particles

Particles in the size range from about 10μm up to about 100μm are termed coarse particles. Most particles in this size range are short lived in the lower atmosphere. Usually the number of these large particles in the atmosphere is small, but they can represent a significant portion of the total mass of particulate matter present in the atmosphere. These are most likely produced from soil and dusts getting suspended in the air, a process that is more prevalent in the summer time in Ireland than at other times of the year.

2.4.4 Contributions to particle mass

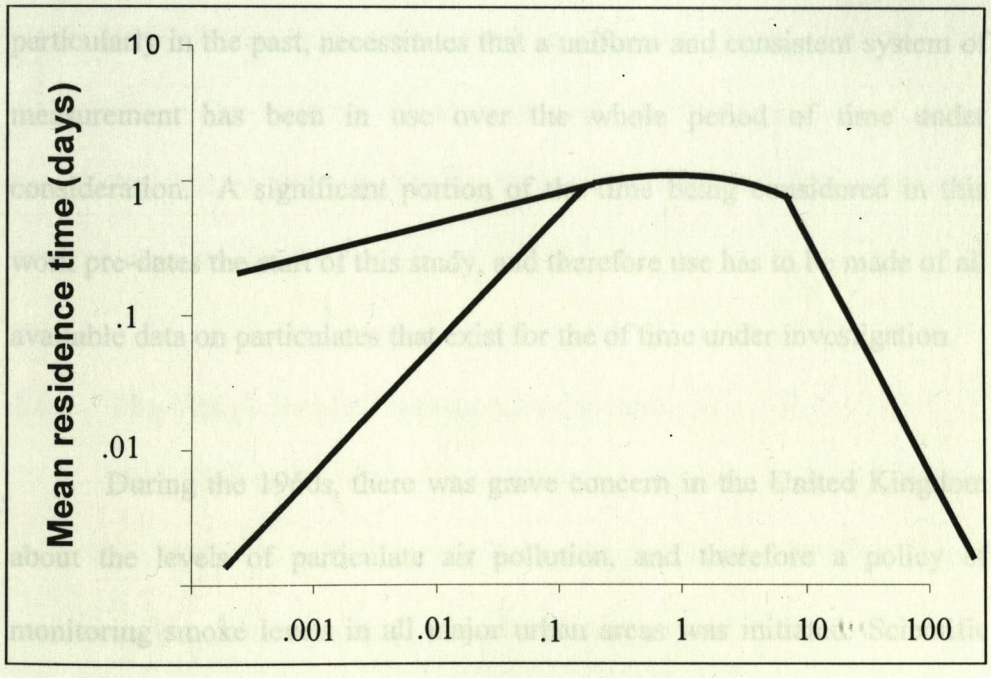
Most pollution measurements are expressed as the mass of particles in μg per m^3 of air. This does not give details of particle size distribution and indeed, a few coarse particles could contribute significantly to the overall mass of particles present. Even in the most remote and unpolluted areas of the word, typical background counts of particle concentrations of 300 particles per cm^3 are common. O`Connor and Mc Govern [5] report that particle concentrations at Mace Head on the West Coast of Ireland are typically in the range 100 to 500 particles cm^{-3}. Because of the prevailing winds and the Atlantic Ocean in close proximity to Mace Head, it is often used to give background pollution levels in European studies. Particle concentrations can be up to 1000 times higher than this in polluted areas. One must be careful when discussing particle pollution levels to be aware of the size distribution of the particles concerned. Coarse particles may make up only 10% of particle numbers but still account for over 90% of the particle mass. The recent UK report [2] states that "ambient particle sampling currently focuses on the mass of particles rather than their number. Recent suggestions, those adverse effects of exposure to ambient particles may be caused by the ultrafine fraction (< 0.1μm) are likely to generate research interest in the measurement of particle numbers".

Although particle mass is mainly used in this study, knowledge of the size cut-off, of the measuring apparatus, may be used to indicate the range of sizes of particles under consideration.

2.5 RESIDENCE TIME OF PARTICLES IN THE ATMOSPHERE

The size of a particle has a strong effect on the length of time the particle stays suspended in the air. As would be expected larger and heavier particles have a short residence time and soon fall back to earth under the influence of gravity (sedimentation). Smaller particles can however remain suspended in the air for a significant period of time.

Residence time of particles in the atmosphere



(adapted from Jaenicke[6])

Diagram 2.1

Jaenicke[6] shows that particles in the size range 0.1μm to 10μm have a mean residence time in the atmosphere in the order of days, while particles > 10μm have a mean residence time of a few hours. Curve A in diagram 2.1 represents particles falling to ground, while curve B includes the effect of

coagulation. The smaller ultrafine particles tend to coagulate to form larger particles, and so their residence time also falls off, that is in the absence of a renewing source. From the perspective of particles, which may interact with the human respiratory system, it is those particles within the size range 0.1μm to 10μm, which are of most interest. It also happens that these are the particles, which have the greatest residency time in the atmosphere.

2.6 MEASUREMENT OF AIRBORNE PARTICULATES

To study particulate pollution levels over a long period of time, particularly in the past, necessitates that a uniform and consistent system of measurement has been in use over the whole period of time under consideration. A significant portion of the time being considered in this work pre-dates the start of this study, and therefore use has to be made of all available data on particulates that exist for the of time under investigation.

During the 1960s, there was grave concern in the United Kingdom about the levels of particulate air pollution, and therefore a policy of monitoring smoke levels in all major urban areas was initiated. Scientific measurements of air pollution had been in use for a considerable period, Meteorological Office (UK) 1917 [7]. But there was a need to specify a standard approach and technique for the measurement of air pollution, and such a standard was introduced by the British Standards Institute as, BS 1747 [8], in 1969. This was to ensure uniformity of measurement at all locations. The system of measurement specified in BS 1747 was relatively cheap to install and maintain, and also easy to operate. This same

measurement technique was adopted by the European Community [9] (80/779/EEC). Implementation of this directive became mandatory in Ireland from the 1st of April 1983. It should be noted that there is a difference in calibration between the EEC system and the BS system, to convert the BS reading should be multiplied by 20/17. All of the measurements used in this study have been converted to the EEC calibration.

In Ireland an urban monitoring network was set up by the Department of the Environment, and is operated by the various local authorities. The method of measurement employed at all of these monitoring stations was based on the BS system. (Details of the monitoring network are given in Chapter 5).

2.6.1 The "Black Smoke" measurement system

The "Black Smoke" [8] measurement system collects ambient particulate matter on a filter, which is located in a special housing. Upon analysis of the filter, a value for the pollution in $\mu g/ m^3$ is obtained. When in use, ambient air is drawn through white filter paper, this filter paper being housed in a special holder. The particles present in the air get trapped on the filter paper. A flow rate of air between $1.5m^3$ and $2.5m^3$ per hour should be drawn through the filter. Typically, air is sampled for a period of 24 hours using the same filter throughout.

On completion of a 24 hour sampling period, the filter is removed from the holder for analysis. The analysis technique used to analyse the filter is based on the reflectance of light from the filter. White light is shone on the filter and the amount of reflected light is measured. The "blacker" or darker the filter the less reflectance, and hence the greater the amount of particulate matter trapped on the filter. A clean white filter is used to first zero the reflectometer, this will give the maximum value of reflectance, filters on which particulate matter is trapped will produce less reflectance. The reflectance reading obtained for the filter used for the collection of particulate matter is compared with the calibration curve given in the BS 1747 specifications. This calibration curve allows for a value of the surface particulate concentration on the filter to be obtained which is expressed in μg of particulate per cm^2 . This value is then entered into the following equation, together with the other parameters, and a value of particulate concentration in $\mu g/m^3$ of equivalence of standard smoke is obtained.

$$C_z = Sa / V \quad \mu g/m^3 \qquad \textbf{(eqt 2.2)}$$

where;

V = volume of air sampled (m^3)

a = area of the stain on the filter paper (cm^2)

S = equivalent surface concentration of smoke on the filter paper, this value is obtained from combining the reflectance reading and the calibration curve.

The BS 1747 system has been adapted to allow for sampling over 8 days, this allows for sampling of up to eight filters in sequence, thus giving the flexibility of only having to attend to each monitoring station once a week, this has significant savings in time and travel where a large monitoring network is involved.

BS 1747 System

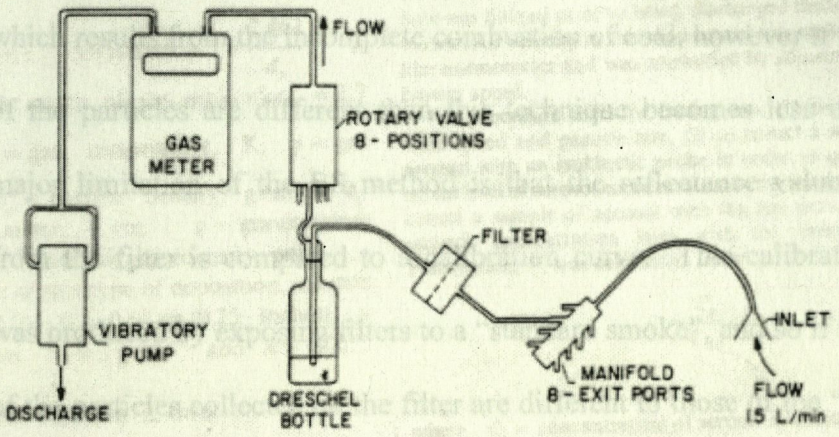


Diagram 2.2

This system of measurement was designed to look primarily at smoke pollution from coal burning and is thus well suited to this study, where the major sources of particulate pollution of interest was viewed as being that from domestic coal burning.

2.6.2 Limitations of the Black Smoke measurement technique

The measurements made using the Black Smoke technique are the only consistent reliable set of readings on particulate pollution levels that exist for complete period of time under consideration in this study. The limitations of this data must be realised.

Lipman and Lioy [10] state that the Black Smoke method of measurement is very good for use in the study of soot in the atmosphere which results from the incomplete combustion of coal, however if the nature of the particles are different then this technique becomes less useful. A major limitation of the BS method is that the reflectance value obtained from the filter is compared to a calibration curve. This calibration curve was produced by exposing filters to a "standard smoke", and so if the nature of the particles collected on the filter are different to those of the "standard" then it is possible that an incorrect estimate of the level of pollution will be obtained. Hamiliton *et al* [11] provide a theoretical approach, which shows that the value obtained from this reflectance method, is proportional to the light absorption coefficient of the material collected on the filter. Since black carbon is the predominant light absorbing substance in the atmosphere, the Black Smoke method effectively gives us a value of the black carbon in the atmosphere. Horvarth [12] states that a dark deposit on the filter can only be obtained from light absorbing particles. So for example, if latex particles (consisting of transparent polystyrene) are sampled on a filter, then the reflectometer will only show a small change in reflectivity even if there are several $100\mu g/m^3$ present. "It is clear" he states "that this system

will give a value of particulate pollution which depends on the light absorbing properties of the particles and little else". Petzold and Niessner [13] also report on the correlation between Black Smoke and black carbon.

The report on the Dublin monitoring network conducted by the Warren Springs Laboratory [3] reports that the major contributor to particulate pollution in Dublin was the burning of coal in open domestic grates. Walsh [14] also conducted studies on the other major solid fuel source in use in Ireland, namely native turf, he reports that the smoke produced from the burning of native turf corresponds extremely well with the calibration smoke of the BS 1747 system. Ball and Hume [15] also report that the BS method of measurement is well suited to the monitoring of particulate emissions from diesel engine vehicles.

Since the use of coal for domestic heating was viewed as the major contributor to particulate air pollution, and since it was intended to evaluate the effects of Government intervention on the use of coal, it was deemed that the measurements made using the Black Smoke technique are suitable for use in this study.

The BS system gives a value as to the mass of particulate matter present in the atmosphere, however it does not provide any information on the number of particles present. Despite these limitations the BS set of measurements are the only complete set of readings of particulate pollution in existence for the places and the time period under consideration in this

study.

2.6.3 The Black Smoke system and particle size

It is important if use is to be made of data produced by the BS system to know how this system compares with other measurement systems, and to the size of particles which can be measured using the BS system.

There have been a significant number of publications in the past few years where reference has been made to what is know as PM_{10}. PM_{10} is defined as Particulate Matter less than 10μm aerodynamic diameter. The importance of particles in this size range to human health is discussed in Chapter 4.

Mc Farland and Ortiz [16] measured the cut-off size of particles, which could be measured using the BS method and they conclude that the BS system has a cut-off at approximately 4.4μm. Lipmann and Lioy [10] also report that the BS system can only measure particles < 4.5μm in size.

Muir and Laxen [17] have proposed a relationship between measurements made using the Black Smoke method and those made of PM_{10}, however their proposal has generated some controversy, Mage [18] and Horvarth [12]. A recent report from the UK [2] shows that there is some correlation between measurements made using the BS system and measurements of PM_{10}, and that these correlation's are stronger in winter time, and are very site specific. Dockery and Pope [19] suggest that as a

guideline for estimating PM_{10} that measurements of BS and PM_{10} are approximately the same. This is also in agreement with comparisons made by the US EPA [20], where the Black Smoke is assumed to be equal to PM_{10} as a lower bound.

2.7 CONCLUSION

In conclusion, measurements of airborne particulate pollution using the Black Smoke method correspond extremely well to a measurement system with a cut-off of approximately 4.5μm, furthermore measurements made using this system approximate well with measurements of PM_{10}, particularly in winter time. As such, data generated by the BS method is suitable for the discussion of health effects of particulate air pollution, and has been used recently in a significant number of other studies [21, 22, 23, 24, 25, 26]. The use of the BS method is also appropriate in view of the nature and sources of particulate pollution in Ireland.

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Chapter 3

PARTICULATE AIR POLLUTION IN IRELAND

3.1 INTRODUCTION

This chapter discusses the specific aspects, which are relevant to the study of particulate air pollution in Ireland and its associated health effects. Geographical, meteorological and demographic aspects are covered in detail, together with relevant socio-economic factors and governmental interventions as they relate to the study of particulate air pollution.

3.2 GEOGRAPHICAL OUTLINE

Ireland is a small island on the western edge of the European continent. To the west of Ireland is the expanse of the Atlantic Ocean. Ireland is 84,000 km^2 in area, and lies between 51.5^0 N and 55.5^0 N and between 5.5^0 W and 10.5^0 W Ireland has a population of approximately 3.5 million people [1]. Increasingly the population is living in larger urban areas. The largest population centres are mainly along the East Coast. Dublin, the capital, is located on the East Coast, and has a population of approximately 1 million [1] people living in the greater Dublin area. The part of Ireland which is of most interest in this study is the main central city area of Dublin, called the Dublin County Borough, the population of Dublin County Borough is approximately half a million people [1]. This represents almost 14% of all of the people living in the Irish Republic. There are some large centres of population away from the east cost, the most important of these

being Cork on the south coast, and Limerick and Galway on the west coast. A map showing the major centres of population is given in appendix I.

Ireland is somewhat "saucer like" with the centre of the island relatively flat, with the mountains mainly in the coastal areas. The highest ranges of mountains are to be found in the south west corner of the island. There are local topographical features, which can produce significant local effects, these where relevant, are discussed in detail in the individual case studies.

The principal mountains have peaks in excess of 600m, with the highest, Carrauntoohil, 1041m above sea level. Roberts [2] reports that about 240 km^2 of the land in Ireland is over 600m above sea level, this is approximately 3% of the land area.

3.3 METEOROLOGY

Ireland has a temperate climate, in that there are generally no major extremes between seasons. Rohan [3] gives a detailed description of the climate of Ireland, and covers the extreme values recorded in all of the major meteorological parameters.

Irelands weather is dominated by the Atlantic Ocean. It is from the direction of the ocean that the prevailing winds come. On average about three Atlantic frontal weather systems cross the country per week. Since these dominating weather systems come such vast distances across water,

they are generally associated with rainfall or precipitation of some sort. The south west corner of Ireland is one of the wettest regions in Europe. The number of days on which rain falls somewhere in Ireland is relatively high. Prolonged spells without rain are scarce, but they do occur, and can be of grave concern to the farming community. In fact there is only one calendar month on record for which no rainfall was recorded for Dublin, and that was in 1801 [3]. The south west is the wettest region with most rainfall, and more days on which rainfall is recorded, the north east and south east are the driest areas.

Because Ireland is surrounded by water, extremes in temperature are uncommon; this is due to the moderating influences of the sea. In wintertime the sea is slow to cool, thus giving some heat to the adjoining land, while in summertime the sea heats up more slowly than the land and thus keeps the adjoining land cool. Since Ireland is a relatively small island most locations are not far from the sea, and hence come under its temperature moderating influences. There are of course seasonal variations, with average summer temperatures of about 15^0C and average winter values of 4.2^0C [3]. The biggest variation in temperature occurs in the midland areas, which are farthest away from the moderating influence of the sea.

As already stated, on average, three frontal weather systems cross Ireland each week. These Atlantic frontal weather systems which cross the country are associated with areas of low atmospheric pressure. This in turn is normally associated with cloudy, wet and windy weather.

The rainfall is a consequence of the fact that these weather systems have to cross so much water before they reach Ireland, and they gather moisture along the way. When these weather systems reach Ireland, it is the first land mass that they encounter, and they deliver considerable precipitation over the country. Ireland does not experience many periods without appreciable rainfall or wind. Any dry sunny periods or spells, which do occur, are unlikely to last for more than two weeks without some interruption.

3.4 METEOROLOGICAL CONDITIONS WHICH FAVOUR THE BUILD UP OF PARTICULATE AIR POLLUTION IN IRELAND

Particulate air pollution in Ireland is a predominately winter phenomenon, in which domestic space heating by open grate burning of solid fuels, is considered to be the primary source of such pollution. The summer time "gas to particle conversion", by the action of intense sunlight on gaseous pollutants, is not considered to be a major source of particulate pollution in Ireland, in contrast to hot sunny locations like Greece or California, where it is a major problem.

During normal winter weather conditions in Ireland, the wind and rain associated with the Atlantic frontal systems which cross the country, act to remove and disperse the particulate pollution (smoke) as it is produced. With the low atmospheric pressure associated with the frontal systems, there are rising air currents, and hot smoke rises up into the atmosphere, and mixes and gets dispersed by the strong winds at high level. The rainfall also

serves to remove particles from the atmosphere by a process known as *wet deposition*, which has been discussed in chapter 2. In wintertime, even if there are significant sources of particulate pollution, the weather conditions are such that the pollution does not get the opportunity to amass, and therefore ambient pollution levels are generally quite low.

There are however particular weather patterns, which can occur in winter time and favour the build up of particulate pollution in the atmosphere. Such patterns are associated with periods of high atmospheric pressure. These high pressure weather systems give rise to slack winds (typically < 2 ms^{-1}), the skies clear of cloud, and hence with no cloud no precipitation can occur. In such circumstances in winter, once darkness falls there is rapid radiative cooling of the ground, and the lower layers of air near the ground surface, (typically the first 35m of the atmosphere). With the ground surface getting so cold, frost formation becomes likely on the ground and other low level surfaces. This can then give rise to a situation known as a *temperature inversion*. In a normal situation as one goes up in the atmosphere away from the earth's surface, the temperature falls, as shown in curve A, figure 3.1, reaching $0^{o}C$ around 2,000m and of the order of minus $50^{o}C$ around 13,000m, the height at which jet aircraft fly. In a typical *temperature inversion* the air near the ground surface cools rapidly, and a layer of air can exist above this which is warmer than the air at the earth's surface, as shown in curve B, figure 3.1.

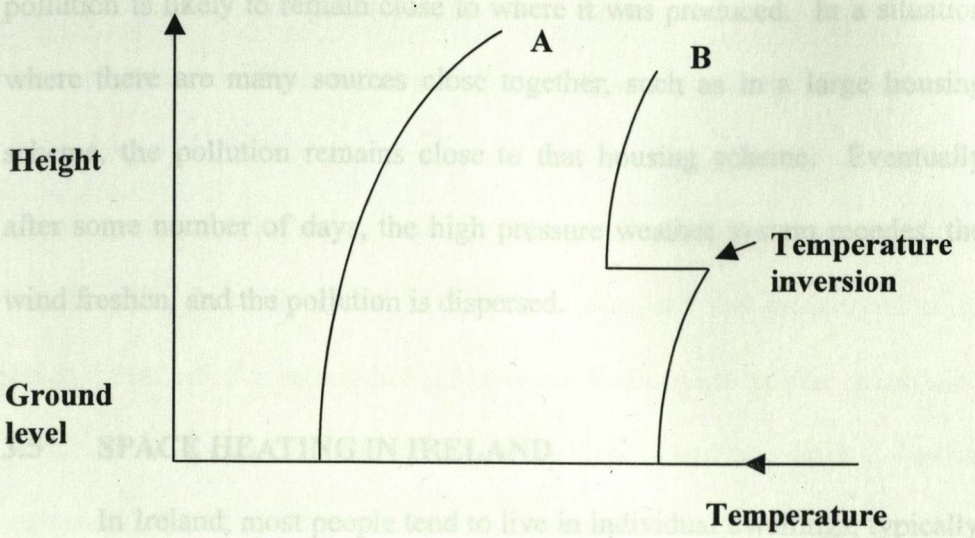


Diagram 3.1

Where a temperature inversion forms, because the ambient temperature is low, and there is widespread frost likely, people are inclined to use even more fuel in their heating systems to counteract the cold, and to maintain the household temperature. This gives rise to even more smoke being emitted into the atmosphere. Smoke emerging from chimneys only climbs to the inversion level, and since the air above this inversion level is warmer, and less dense than the smoke, the smoke stops rising, and effectively becomes trapped by the inversion layer. The inversion layer acts like a lid on the lower atmosphere. Since the weather pattern which gives rise to the development of a temperature inversion is also associated with slack winds, the pollution levels in the lower atmosphere tend to build up, as the sources continue to emit pollution, and there is no mechanism present for the dispersion of the pollution. When such weather patterns occur in winter, they can last for typically from 5 to 10 days, and they are associated

with spells of high particulate pollution. Because of the slack winds, the pollution is likely to remain close to where it was produced. In a situation where there are many sources close together, such as in a large housing scheme, the pollution remains close to that housing scheme. Eventually after some number of days, the high pressure weather system recedes, the wind freshen, and the pollution is dispersed.

3.5 SPACE HEATING IN IRELAND

In Ireland, most people tend to live in individual dwellings, typically two stories high. Large apartment blocks have not been common until recent times. Almost all dwellings have their own individual space heating systems. Commercial or centralised area space heating systems are virtually unheard of in Ireland. This gives rise to the situation where there are potentially numerous small sources of particulate pollution as opposed to one or two large sources. Ireland does not have a history of heavy industry, and in fact, agriculture formed the basis of most commercial activity until recent years. As a consequence, sources of pollution associated with smelting and heavy engineering are not to be found in this country. In fact the Warren Springs report [4] states that the burning of coal in open domestic grates is the greatest source of airborne particulate pollution in Dublin, and by extension this statement can be applied to all other large urban areas in the country. The fact that almost every individual dwelling is a potential source of airborne particulate pollution, and since most domestic chimney stacks are no more than 10 m high, any pollution emitted from them is virtually certain to be trapped by an inversion layer when one is present.

Traditionally industry has used very high chimney stacks to emit smoke from industrial processes, this is to ensure that the plumes from the chimneys disperse their effluent well away from the source, making use of the stronger winds which are prevalent as one ascends in the atmosphere. Furthermore, a tall chimney stack could reach above an inversion layer, enabling the plume from the chimney to escape, and not get trapped at the lower level of the atmosphere. However since most of the particulate pollution in Ireland is attributable to domestic sources, high industrial chimney stacks will not provide any major improvement in air quality.

3.5.1 Types of space heating systems

The burning of coal, turf or wood in an open grate was the main source of space heating in Ireland. Town gas was available in about 80% of homes, but most only used it for cooking purposes, and at best about 20% of customers used it for space heating [5,6]. As new housing schemes developed during the 1970s oil based heating systems were popular. The oil based systems were particularly useful in large houses, although almost certainly most houses with this type of heating also had open grate fireplaces.

The use of electricity for space heating is extremely limited since it tended to be significantly more expensive than the alternatives [7].

3.5.2 Housing in Ireland

Housing in Ireland falls into two main categories, *private* and *local authority.* The policy in local authority housing up to the mid 1980s was not to install space heating except those based on solid fuel using a back boiler and open grate arrangement [8]. Local authority housing was typically built to a higher density than that of private dwellings, with local authority schemes typically having over 300 houses in each scheme. A large number of dwellings in close proximity, each with their own solid fuel heating systems provided a significant potential source of airborne particulate pollution. Any environmentally friendly heating systems were exclusively based in private housing schemes.

Oil crisis of the 1970s

During the 1970s the oil crisis, which affected the whole world, oil, supplies were restricted by the main producers and the price of oil rose. In Ireland, the government responded by trying to reduce the nations dependence on oil, since all oil consumed within the state was imported. The government introduced legislation [9] (appendix II), to provide state grants to assist householders to convert their heating systems from the more expensive imported oil to solid fuel. This policy further compounded the potential for airborne particulate pollution by increasing the number of dwellings depending on solid fuel as their form of space heating. Convery [8] gives the following breakdown for the types of space heating in use in Dublin in 1983.

Domestic heating systems in Dublin in 1983 by fuel type

HEATING SYSTEM	Private %	Local %
OIL	3	0
OIL and BACK BOLIER	27	0
SOLID FUEL	73	100
GAS	1	0
ELECTRICITY	0	0
NONE	0	0
	100%	100%

Table 3.1

Another compounding factor was that people liked the warmth and glow of an open fire [10], a fact, which was exploited in advertising at the time extolling the virtue of solid fuels. There was virtually no acceptance by the consumer of the use of closed stoves with solid fuel, despite the fact that such stoves are more efficient in producing heat, give fuller combustion of the fuel, and reduce particulate emission levels.

This was the situation in Ireland in the 1980s, and with clear evidence emerging from Kelly and Clancy [11] that during episodes of temperature inversions that people were dying from exposure to the elevated pollution levels. The numbers of such excess deaths have been quantified by Clancy et al.[12] in a retrospective study.

A further factor influencing the widespread use of coal was that it was widely available and relatively cheap. Coal could be bought in small

amounts when required with a 25kg bag costing typically £3.80 in 1985; oil on the other hand could only be bought in large quantities with a typical minimum delivery costing £100. This cost situation meant that most could not afford to buy oil, and relied on coal instead. The following table from Reilly [7] gives the comparative costs of producing the same energy output from differing fuel types, the figures are based on 1985 costs, and since 1985 is near the middle of the period of time under consideration in this study, these figures are viewed as being acceptable for comparison purposes.

Domestic Fuel Costs Dublin July 1985

Fuel Type	Cost (p/kWh)
Liquid Fuels	
Gas Oil	2.88
Kerosene	3.01
LPG (Propane)	5.65
Solid Fuels	
Antracite (Blend)	2.28
Extracite	2.47
Household Coal	1.65
Peat	1.93
Peat Briquettes	1.63
Electricity	
General Domestic	7.85
Economy (night 11.00pm-8.00am)	3.80
Natural Gas	
(various charges) Typically	3.00

Table 3.2

Domestic heating systems in Dublin in 1983 by fuel type

HEATING SYSTEM	Private %	Local %
OIL	3	0
OIL and BACK BOLIER	27	0
SOLID FUEL	73	100
GAS	1	0
ELECTRICITY	0	0
NONE	0	0
	100%	100%

Table 3.1

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Electricity	
General Domestic	7.85
Economy (night 11.00pm-8.00am)	3.80
Natural Gas	
(various charges) Typically	3.00

Table 3.2

This table is particularly useful in that it compares the actual cost (in Irish pence) of producing 1kWh of energy from the various types of fuel typically in household use at the time. The table shows that coal and turf are significantly cheaper than most other types of fuel, and thus coal in particular has for long been the most favoured fuel for space heating in Ireland, and especially in Dublin. This reliance on coal however compounds the problems when one is concerned with particulate emissions into the atmosphere. It is not surprising that it was domestic coal burning which was the subject of legislation to reduce emissions of particulates, this legislation is discussed further on in this chapter.

3.5.3 Socio-economic concerns in air pollution studies

There is concern that socio-economic status can play a major role in the susceptibility of a person to ill health, or even death, as a consequence of exposure to pollutants. Davey Smith et al.[13], Mackenbach [14] and Sexton et al.[15] have investigated the effects socio-economic status can have on susceptibility to pollution events. Whitehead [16] says that it is "unfair" as those in a lower socio-economic class are often more susceptible, and at the same time are more exposed to air pollution.

In this study it has not been possible to separate mortality data into different socio-economic groups. This however is not viewed as a disadvantage, because the exposure and effects have been studied over the whole population. Furthermore this work is particularly interested in the investigation of the effectiveness, or otherwise, of controls introduced to

reduce pollution levels. Thus if the whole population is studied, both before, and after interventions have occurred, then one does not have to worry too much about the socio-economic grouping of the population. It should also be noted that lower socio-economic class is not always an indicator for susceptibility, Kaplan and Mascie-Taylor[17] report that higher susceptibility to asthma may exist in a higher socio-economic class. The EC report [18] gives a detailed discussion on socio-economic status and its relationship to health effects from air pollutants. Englert [19] accepts that the current type of time series studies on the health effects of airborne particulate pollutants, which study total populations, like that of Schwartz [20], seems reasonable. This is consistent with the approach being adopted in this study.

3.5.4 Natural Gas Supplies

Natural gas was discovered off the south coast of Ireland near Kinsale in the 1970`s. This was piped to Dublin, with the first households getting connected to the system in 1984. There has been an active policy of persuading people to switch their space heating systems to natural gas since then. Virtually all new dwellings built in the greater Dublin area since 1984 rely on natural gas as their source of space heating. As local authority housing is refurbished, natural gas systems have been installed, and there are attractive financial packages to encourage privately owned dwellings to convert to natural gas heating.

Despite the advent of natural gas in Dublin, particulate pollution episodes were becoming commonplace during the winter months in the mid to late 1980s. There were noticeable reductions in visibility, with strong smells of smoke and soiling of buildings and clothing associated with episodes of particulate pollution. It became obvious that some form of intervention was required to reduce pollution levels and improve the environment. Various groups [6] discussed how best to tackle this problem. Recommendations ranged from widespread conversion to other fuel types to the introduction of selective smoke-free zones.

3.6 LEGISLATIVE INITIATIVES TO REDUCE PARTICULATE POLLUTION

The Irish government introduced the Air Pollution Act in 1987 [21], this allowed for the development of a comprehensive framework for the control of air pollution. This act was to be used to allow for the introduction of more specific legislation as required.

3.6.1 Ballyfermot

Ballyfermot is a large local authority housing scheme on the west side of Dublin. This area experienced some of the highest pollution levels throughout the 1980s. A trial smoke-free zone was introduced to cover the Ballyfermot area in 1988 [22,23,24,25,26]. This trial did not prove very successful, an outcome attributed mainly to the cost of the smokeless coal being greater than that of ordinary coal. The residents complained that the smokeless coal was difficult to light, and that the higher temperatures

generated by the smokeless coal caused damage to grates. It was also found to be extremely difficult to monitor and enforce the policy of smoke-free zones, a problem still being experienced in Belfast [27] where smoke-free zones are still the norm.

3.6.2 Other air quality legislation

It became obvious that the smoke-free zone approach as tried in Ballyfermot was having only a limited effect and that there was a need for a different strategy to tackle the problem of particulate air pollution in Dublin as a whole. An enlightened approach was forthcoming with the introduction of the Air Pollution Act, 1987 (Marketing, Sale and Distribution of Fuels) Regulations, 1990 [28]. This act banned the sale, marketing and distribution of bituminous coal in the greater Dublin area from the 1st September 1990. This ban meant that bituminous coal could not be sold or purchased within the greater Dublin area. It was not illegal to use such coal, but householders would experience great difficulties in obtaining supplies. This legislation is much easier to monitor and enforce than the smoke-free zones discussed earlier. Since bituminous coal was not available, people had no alternative but to switch to other forms of fuel.

As already mentioned the approach in Belfast has been to introduce smoke-free zones, but since bituminous coal is readily available, Belfast continues to experience particulate pollution problems [27]. The evidence from Dublin suggests that this legislation has proved to be extremely effective in reducing particulate pollution levels. The consequences of the

introduction of this legislation for health are discussed in detail later in this report.

Similar legislation [29] regarding the use of bituminous coal was introduced to cover Cork, the second largest city in Ireland. This came into effect in 1995. This followed a period of local campaigning [30] to have legislation similar to that, which had been introduced in Dublin [28], extended to cover Cork. Mc Gettigan et al [31] report that the extension of this legislation to cover other large urban areas might be warranted, and such an extension has been strongly recommended by Clancy et al. [32]. This ban on the use of bituminous coal has recently (winter 1998/99) been extended to cover a number of other major urban area which had not been included in the previous legislation [33].

3.7 FUEL USAGE IN IRELAND 1980-1996

The type of fuel being used is considered to be significant in relation to the ability to cause air pollution, as evidenced by the Warren Spring report [4], which blames the burning of coal in open domestic grates as the main contributor to airborne particulate pollution in Dublin. Furthermore, the legislative approach adopted by the Government [21,28,29] targeted bituminous coal as the major contributor to air pollution, and banned its sale and distribution in designated areas. In view of these developments, it is appropriate that the trends in fuel usage in Ireland over the period under consideration in this study be investigated. The only indigenous fuel types widely used and available in Ireland are turf and natural gas, and therefore a

significant portion of fuel has to be imported.

3.7.1 Energy in Ireland 1980-1996, a Department of Transport, Energy and Communications report.

Myres [34] has compiled a report on fuel usage in Ireland from 1980-1993. This is an extremely comprehensive report, the main findings of which are summarised here. The Myres report is based on fuels used within a given calendar year. For the period from 1994 to 1996 the data was obtained directly from the Department of Energy, some of this information is also available on line [35].

3.7.2 Total energy consumption 1980-1996

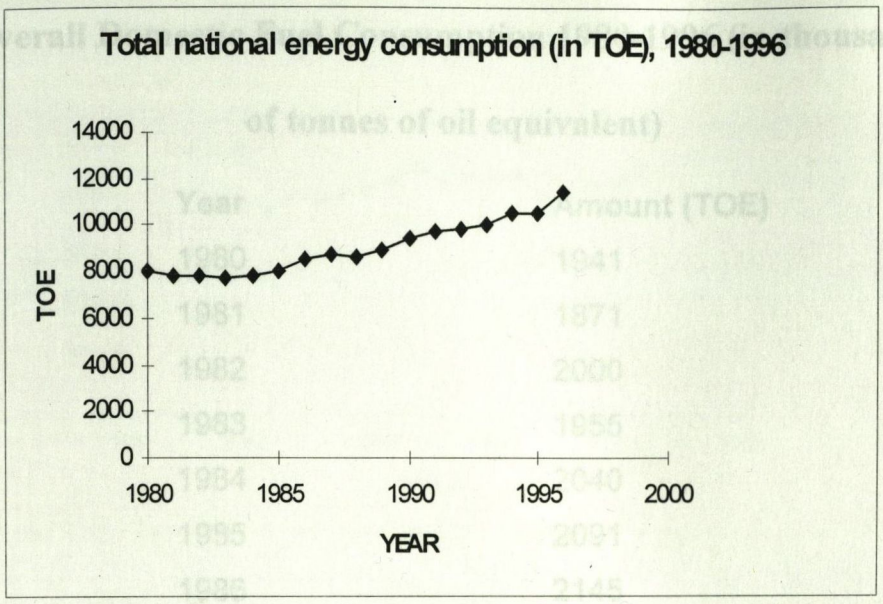
For ease of comparison all the fuels have been converted to what is called "tonnes of oil equivalent", (or TOE), which is an International Standard measurement of energy value. The following table, table 3.3 gives the total fuel consumption for Ireland in TOE for each of the years from 1980 to 1996.

Total fuel consumption

Year	TOE
1980	8047
1981	7795
1982	7806
1983	7671
1984	7817
1985	8050
1986	8548
1987	8763
1988	8624
1989	8973
1990	9420
1991	9708
1992	9852
1993	10007
1994	10522
1995	10564
1996	11453

Table 3.3

These above data are plotted in **graph 3.1,** this graph clearly shows that there has been a general upward trend in fuel consumption over the period, with an overall 24% increase from 1980 to 1996, while the overall increase in population over this period was less that 6%.



Graph 3.1

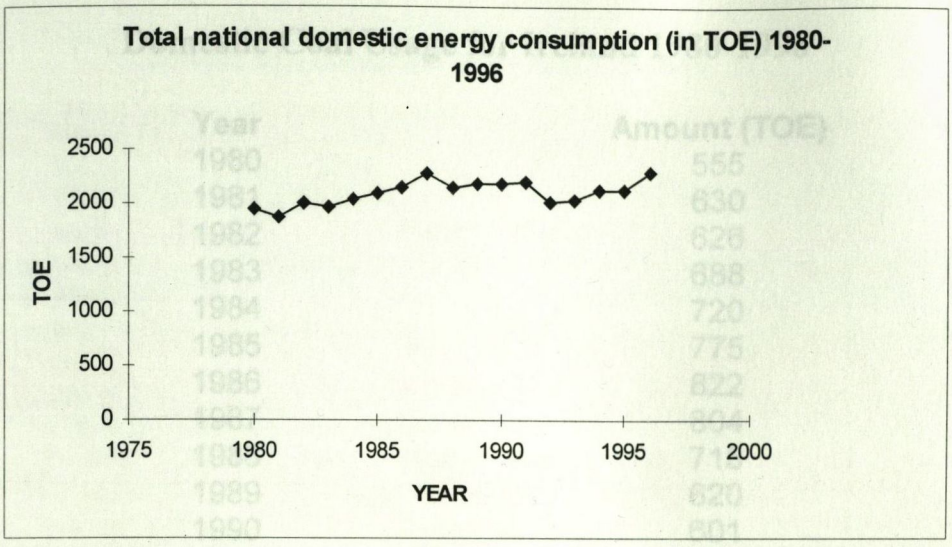
3.7.3 Domestic Fuel Consumption

Domestic fuel consumption has changed little from 1980 to 1996, showing only an 18% rise, with most of this rise occurring since 1993.

Overall Domestic Fuel Consumption 1980-1996 (in thousands of tonnes of oil equivalent)

Year	Amount (TOE)
1980	1941
1981	1871
1982	2000
1983	1955
1984	2040
1985	2091
1986	2145
1987	2279
1988	2141
1989	2179
1990	2190
1991	2209
1992	2011
1993	2042
1994	2137
1995	2127
1996	2300

Table 3.4



Graph 3.2

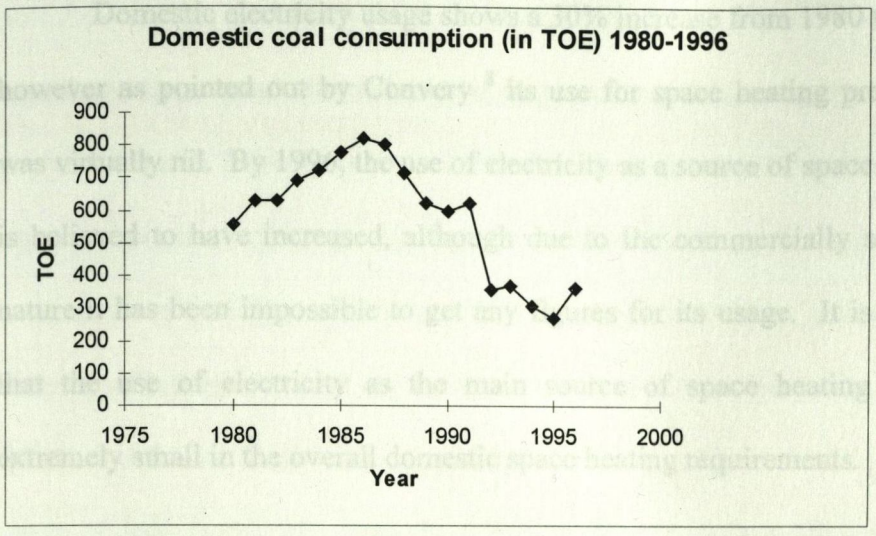
However, the distribution of fuel types used in domestic consumption shows significant changes. Domestic coal usage, which is of particular interest since it was viewed as the major contributor to airborne particulate pollution, shows an extremely interesting pattern. From 1980-1996 there is a 34% reduction in the domestic usage of coal, although from 1980-1986 there was a 48% increase in domestic coal usage, this reached a maximum in 1986. From 1986 domestic coal usage started to decline, dropping to less than half of the 1986 value by 1996. Half of this reduction occurred over the two-year period from 1991 to 1993, which followed the introduction of the legislation [28].

Domestic Coal Usage for Ireland 1980-1996

Year	Amount (TOE)
1980	555
1981	630
1982	626
1983	688
1984	720
1985	775
1986	822
1987	804
1988	718
1989	620
1990	601
1991	620
1992	358
1993	367
1994	308
1995	269
1996	364

Table 3.5

The trends in domestic coal usage in Ireland over the period are displayed in the following graph



Graph 3.3

At the same time that domestic coal usage was starting to decline after 1986, the availability of natural gas was growing rapidly. Over half of the reduction in the residential use of coal between 1986 and 1996 was replaced by natural gas usage. Over almost the same period from 1985 to 1996, there was a 66% increase in the domestic usage of oil over the 1985 level. These switches to natural gas, and to oil for domestic heating, account for the major reduction in domestic coal usage. It must be noted that the figures quoted for domestic fuel consumption relate to the whole country, therefore most of the reduction in domestic coal usage can actually be attributed to the ban on bituminous coal in the greater Dublin area.

One point of interest is that turf, the use of which was allowed in the initial smoke-free zones [23], shows little change in total usage from 1980 to 1996, but its use increased significantly in 1989 and 1990, during the period of the special control areas [22, 24, 25, 26].

Domestic electricity usage shows a 30% increase from 1980 to 1996, however as pointed out by Convery [8] its use for space heating previously was virtually nil. By 1996, the use of electricity as a source of space heating is believed to have increased, although due to the commercially sensitive nature it has been impossible to get any figures for its usage. It is believe that the use of electricity as the main source of space heating is still extremely small in the overall domestic space heating requirements.

Despite the fact that domestic coal usage has shown a dramatic decline since 1986, the overall usage of coal has actually risen since then. All of this rise in coal consumption is attributable to the commissioning of the Moneypoint power station in Co. Clare by the Electricity Supply Board (ESB). It commenced power production in 1985, but only got up to full production in 1987. The contribution of Moneypoint to airborne particulate pollution in locations like Dublin or Cork, which are far away from the power station, is not felt to be significant.

The impact of the legislation banning the use of bituminous coal in Dublin [28] is assessed later in this report.

3.8 DISCUSSION

This chapter has considered the various physical, social, economic and meteorological factors, which are relevant to the production of particulate air pollution in Ireland. It has been shown that with favourable meteorological conditions, and with a high usage of solid fuels that air

pollution events are likely. This is particularly so when there are a significant number of sources, such as large scale coal burning in a densely populated area. It has also been shown that the cost of fuel gave rise to a high dependence and usage of coal for domestic heating. As natural gas became more widely available in Dublin during the 1980`s, and with the banning of bituminous coal, there was a switch to natural gas from coal and other solid fuels. There was a significant decrease in the national domestic usage of coal, from 1986 onwards, with a marked drop from 1991; most of this drop in coal usage is attributable to the coal ban in Dublin. If Dublin particulate pollution levels are shown to fall with the introduction of the coal ban, then the coal usage can be implicated in the production of particulate pollution in Dublin.

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Chapter 4

THE HUMAN RESPIRATORY SYSTEM AND PARTICLE DEPOSITION WITHIN THE RESPIRATORY SYSTEM

4.1 INTRODUCTION

This chapter is comprised of two main sections; the first section gives an overview of the anatomy of the human respiratory system, discussing the role or function of the various parts. The second section studies the interaction and deposition of particles within the respiratory system. It also investigates how particle size can affect the way in which it interacts with the respiratory system and correlates this with the size of particles commonly found and measured in the atmosphere.

4.2 FUNCTIONS OF THE RESPIRATORY SYSTEM

The human body needs oxygen for it to survive and function; oxygen is carried by the blood to the cells in the body where it is consumed to produce energy. A by-product of this process is the production of carbon dioxide. The respiratory system serves to bring air containing oxygen, to the exchange surfaces and to remove air containing carbon dioxide. These exchange surfaces are part of the respiratory system, and are the location within the lungs where the oxygen and carbon dioxide are exchanged between the circulatory system and the air. Apart from the functions listed above, the respiratory system maintains an appropriate humidity level to facilitate gas exchange, incoming air is also heated, and this too helps with

the gas exchange process. The respiratory system also acts to protect itself and other tissue from invasion by pathogenic micro-organisms. The respiratory system facilitates speaking and assists in the regulation of blood volume, blood pressure and in the control of body fluid pH values.

4.3 ANATOMY OF THE RESPIRATORY SYSTEM

A number of text books [1,2] have been consulted in the preparation of the first part of this chapter dealing with the anatomy of the human respiratory system. The respiratory system is often described as having two component sections, *the upper respiratory system* and *the lower respiratory system.* The upper respiratory system consists of the nose, nasal cavity, paranasal sinuses and the pharynx. The remainder of the system namely the larynx, trachea, bronchi and lungs form the components of the lower respiratory system. There are two main roles performed by the respiratory system, *conduction* and *respiration.* The conduction portion extends from the entrance to the nasal cavity to the bronchioles of the lungs. The respiratory portion consists of the bronchioles and the alveoli, where the gas exchange occurs.

4.4 THE RESPIRATORY EPITHELIUM

The respiratory epithelium lines the entire respiratory tract except for the very fine conducting portions and the alveoli. It consists of pseudostratified, ciliated columnar epithelium with numerous goblet cells. The goblet cells and mucous glands produce a sticky mucous which coats the exposed surfaces. The main role of the epithelium is in the filtration of

air entering the respiratory system and in the humidification of that air. Any debris which gets into the respiratory system and which is then trapped in the mucus, namely particles and micro-organisms, are swept towards the pharynx by the action of the cilia, where it will be swallowed and exposed to the acids within the stomach. In the case of the lower respiratory system the cilia produce a sort of escalator effect moving the debris upwards towards the pharynx again. In the nasal cavity, filtration of particles and micro-organisms is achieved by the coarse hairs, which can capture large particles such as sand, sawdust and insects, while smaller particles can be trapped in the mucus.

4.5 COMPONENTS OF THE UPPER RESPIRATORY SYSTEM

The major components of the upper respiratory system will be described and the role that they play within the process of breathing will be outlined in the following sections.

4.5.1 The nose and nasal cavity

The nose is the primary passageway for air entering the respiratory system. Air normally enters via the paired external nares that open into the nasal cavity. The epithelium of the outer part of the nose, a region called the vestibule, contains coarse hairs which extend across the opening of the nares, and these hairs act to filter out large particles and prevent them from entering the respiratory tract. For air to pass from the vestibule to the internal nares it tends to flow between adjacent conchae, through the superior, middle or inferior meatuses. These are not really open

passageways but rather narrow groves, this causes incoming air to bounce off the conchal surfaces, and to swirl around. This turbulent air flow will give rise to the larger particles which are present in the air, impacting on the surfaces, and getting trapped within the mucus which coats the nasal cavity. This acts to filter out larger particles from the air flow. This turbulent motion also prolongs the period that the air mass spends in the nasal cavity, this extra time facilitates the warming and moistening of the air.

4.5.2 The Pharynx

The pharynx is the name of the chamber in the respiratory system where the nose, mouth and throat connect to each other. It is a shared area between the respiratory and digestive systems. The pharynx extends from the internal nares to the openings of the larynx and oesophagus. The pharynx consists of three main sections, the *nasopharynx*, which is nearest to the nasal cavity and is lined with typical respiratory epithelium cells. The *oropharynx* is the area nearest to the oral cavity, and the cell types here are more like the stratified squamous epithelium of the oral cavity than of a respiratory epithelium. The third section is the *laryngopharynx* and this is closest to the entrance to the oesophagus, the cells lining the laryngopharynx are of a stratified squamous type, which can resist mechanical abrasion, chemical attack, and pathogenic invasion.

Overview of human respiratory system

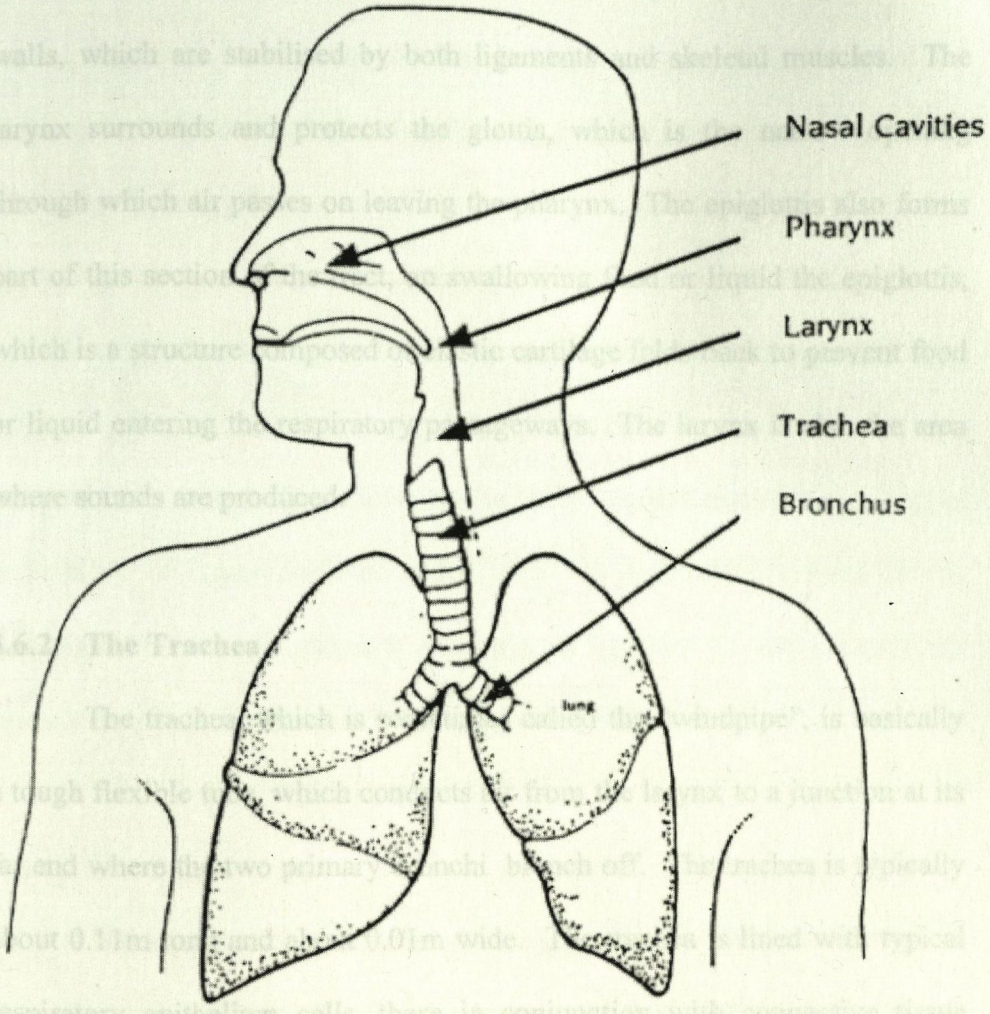


Diagram 4.1

4.6 COMPONENTS OF THE LOWER RESPIRATORY SYSTEM

The main components of the lower respiratory system consist of the larynx, the trachea, the bronchi, the lungs, and the alveoli, where the gas exchange occurs.

4.6.1 The larynx

The first part of the lower respiratory tract that air entering the body encounters is the *larynx*. The larynx is essentially a cylinder with strong walls, which are stabilised by both ligaments and skeletal muscles. The larynx surrounds and protects the glottis, which is the narrow opening through which air passes on leaving the pharynx. The epiglottis also forms part of this section of the tract, on swallowing food or liquid the epiglottis, which is a structure composed of elastic cartilage folds back to prevent food or liquid entering the respiratory passageways. The larynx is also the area where sounds are produced.

4.6.2 The Trachea

The trachea, which is sometimes called the "windpipe", is basically a tough flexible tube, which conducts air from the larynx to a junction at its far end where the two primary bronchi branch off. The trachea is typically about 0.11m long and about 0.01m wide. The trachea is lined with typical respiratory epithelium cells, these in conjunction with connective tissue called the lamina propria form part of the system for removing debris from the trachea. The trachea is surrounded by annular ligaments, which provide strength and rigidity to the trachea. There is a muscle attached to the trachea called the *trachealis,* as this muscle contracts it can alter the diameter of the trachea, which in turn can alter the resistance to airflow, and thus the flow of air can be altered. The trachealis is primarily controlled by the sympathetic division of the autonomic nervous system. Stimulation of the sympathetic nervous system because of matter present in the air can

cause the airflow characteristics of the trachea to alter.

4.6.3 The primary bronchi

At its lower end the trachea branches into two tubes called the primary bronchi, one going to the left lung, the other towards the right lung. The ridge forming the separation between the bronchi is called the carina. A junction such as this, which causes the airflow to branch, can give rise to particle impaction and deposition in the area near the branching. The right primary bronchus generally has a larger diameter than the left, and it also descends at a steeper angle towards the lung, this can give rise to a higher probability of larger particles which enter the respiratory system getting deposited in the right primary bronchus as opposed to the left primary bronchus. The primary bronchi are outside of the lungs.

4.6.4 The lungs

The respiratory system has two lungs, one on the left side of the body the other on the right. The lungs are contained or housed in what are called the pleural cavities. The base of each lung rests on the top of the diaphragm. Each lung consists of lobes, the right lung has three lobes the superior, middle and inferior. The left lung has only two lobes. The left lung is narrower and longer than the right lung, this is due to the heart projecting into the left pleural cavity, and to the liver pushing up the diaphragm under the right lung.

4.6.5 The bronchi and bronchioles

As the primary bronchi enter the lungs they divide into smaller passageways which in turn divide into yet smaller again passageways and so on. These smaller passageways are called the bronchi and bronchioles. This branching or dividing into smaller passageways differs slightly between the two lungs. There can be up to about 23 divisions from the primary bronchi to an alveoli where the gas exchange occurs. There can be typically 6500 bronchioles within the lungs; these would have diameters in the range 3×10^{-4}m to 5×10^{-4}m. The smallest bronchioles deliver air to a single lobule, and the bronchiole divides within the lobule to form several respiratory bronchioles. These respiratory bronchioles deliver air to the exchange surfaces and are the smallest and most delicate branches of the bronchial tree.

THE BRONCHIAL TREE

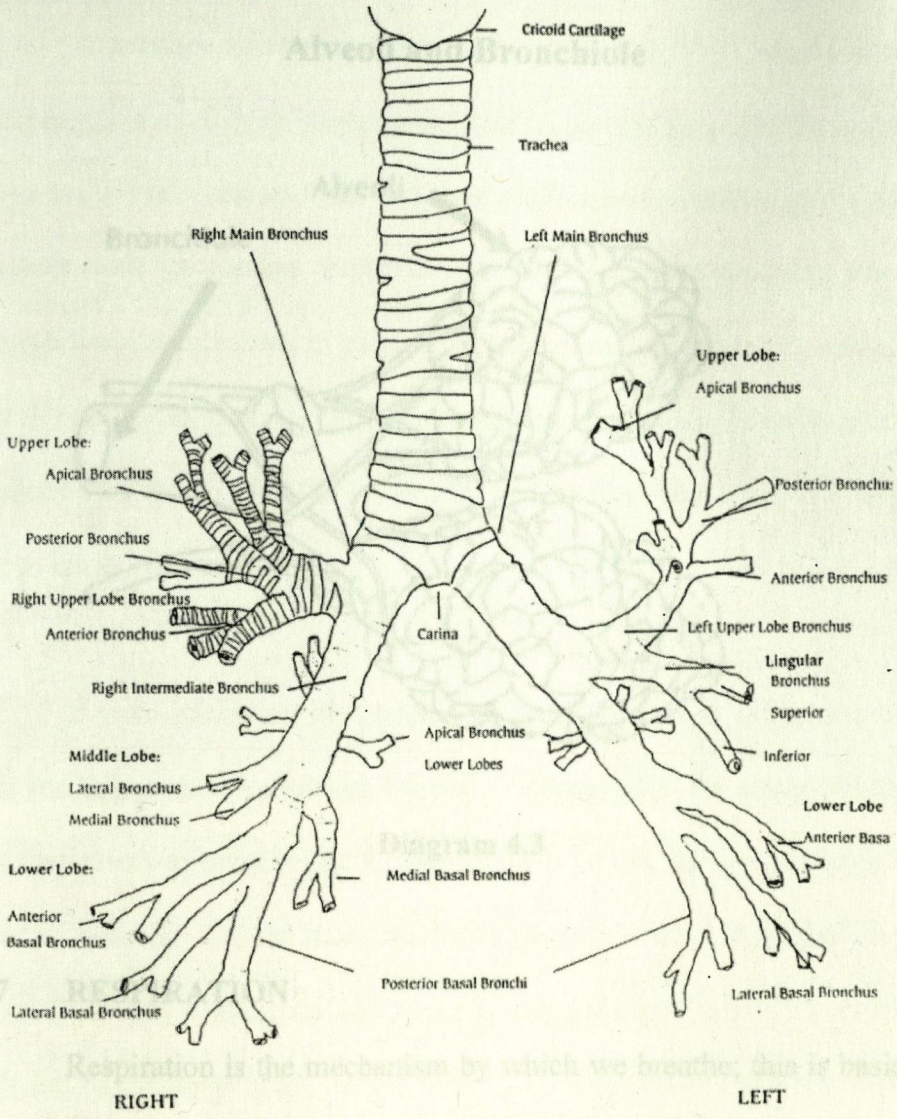


Diagram 4.2

4.6.6 Alveoli

Each lung contains approximately 150 million alveoli, each of which is associated with an extensive network of capillary cells. It is at the surfaces of the alveoli that the gas exchange between the air and the blood occur. Within the alveoli the distance separating the respiratory and circulatory systems can be as little as 0.1μm, and gas exchange, can take

place rapidly by diffusion, due to the short distance involved.

Alveoli and Bronchiole

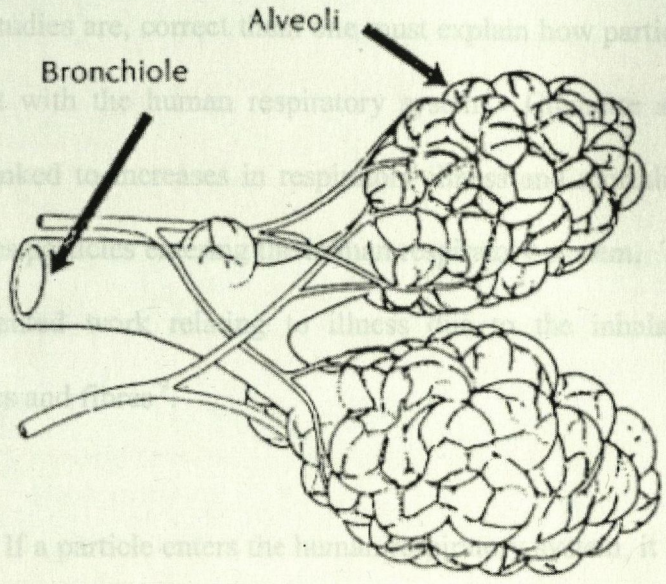


Diagram 4.3

4.7 RESPIRATION

Respiration is the mechanism by which we breathe; this is basically the sucking of air containing oxygen into the body and the expulsion of air containing carbon dioxide. As explained above the incoming air is filtered and moistened before it reaches the exchange surfaces of the alveoli. Breathing occurs under the control of the autonomic nervous system, however voluntary muscle input can also occur. To breathe the diaphragm relaxes, this produces a partial vacuum which serves to suck air into the respiratory system, as the diaphragm contracts it forces the air, containing carbon dioxide, out of the body, this cycle continues as long as the body is alive.

4.8 PARTICLE INTERACTIONS WITH THE RESPIRATORY SYSTEM

A number of studies have been published [3,4,5,6] which attribute increases in mortality to increases in ambient particulate pollution levels. If these studies are, correct them one must explain how particles in the air can interact with the human respiratory system. Cigarette smoking has also been linked to increases in respiratory illness and mortality [7,8]; again, this involves particles entering the human respiratory system. There is plenty of documented work relating to illness due to the inhalation of airborne particles and fibres [9].

If a particle enters the human respiratory system, it seems reasonable that the larger particles will be trapped or deposited in the upper regions of the respiratory system, in that the particle may be too big to pass through the smaller bronchi. On the other hand, if a particle is extremely small it may pass all the way into the alveoli, where it may get deposited, or where it may pass out of the lungs again during expiration. Therefore, if someone breaths in air which contains particles some of these particles are likely to interact with the human respiratory system. The location within the respiratory system where they interact is likely to be strongly related to the size of the particles concerned. Whether these particles get filtered and removed rapidly from the respiratory system or whether they are trapped in the respiratory system is also important.

To illustrate this point, the following two illustrations are very useful, the first illustration, 4.1, shows the lungs of a 1 year old male, who died in a motor accident, contrast these with illustration 4.2, which show the lungs of a man who died in his 70`s and who worked in a steel mill. The lungs of the older male are noticeably blacker due to the build up of particles within the lungs over time. In the case of the older male, although he worked in a highly polluted environment, the illustration still demonstrates that particles build up in the lungs over time. Of course, the amount of build up must also relate to the individuals accumulative lifetime exposure.



Illustration 4.1



Illustration 4.2

4.9 RESEARCH STUDIES

Amelung and Landsberg [10] reported that the when polluted air is inhaled, that the concentration of particles in the exhaled air is less than that of the inhaled air, indicating that some particles are retained in the respiratory system. Burke and Nolan [11] conducted similar experiments in Dublin, they observed that the particle content in exhaled air was always less than that of the inhaled air, they also reported that if filtered air was breathed, that there was no production of particles from the respiratory system. These two studies show that at normal breathing and at ambient particle concentrations that particles get retained in the human respiratory system.

The principal physical mechanisms by which particle deposition can occur in the human respiratory system, has been reviewed [12], there are five mechanisms listed, *impaction, sedimentation, diffusion, interception and electrostatic precipitation.* Some of these are the same as the interactions that remove particles in the ambient environment, and which have been described earlier.

(i) Impaction

Impaction is due to the inertia (speed and mass) of the particle, as there is a change in the direction of the airflow, the larger particles because of their inertial are unable to follow the change in airflow and impact (or collide) with a surface wall. Impaction is likely at a bifurcation of the airway. Impaction as already mentioned is of importance to larger particles,

and particularly so in the upper airways. Because these regions of the upper airway are lined with mucous, the removal of these impacted particles is mainly by mucocillary action. It has already been mentioned (4.4.1) that impaction of particles in the nasal cavity is an important removal mechanism, to remove particles, which are present in, inhaled air.

(ii) Interception

This is similar to impaction, it occurs where the direction of particles does not deviate as rapidly as the airflow, and the particle comes into contact with the surface wall of the airway.

(iii) Sedimentation

This mode of particle deposition is important where the particle (airflow) velocity is low. Sedimentation is important as regards deposition within the bronchioles, however compared with impaction its deposition efficiency is low. The report by the Task Group on Lung Dynamics [13] shows that the lowest deposition rate occurs for particles with a diameter of around 0.5μm. This is related to sedimentation, as deposition by sedimentation is a function of the particle diameter, and sedimentation is the main mode of deposition for particles of size of about 0.5μm, this shows that deposition efficiency for sedimentation is low.

(iv) Diffusion

Very small particles, less than 0.1μm, experience bombardment by air molecules, and so travel in a zig-zag like pattern, from collision to collision. This is the main interaction of such small particles and is the most prevalent deposition mechanism in the alveolar region. This bombardment by air molecules, also called *Brownian motion*, enables the particles to collide and get deposited on the walls of the alveoli.

(v) Electrostatic precipitation

Quite often particles will possess an electric charge, if a number of particles have a like electric charge they will repel one another, this will have the effect of moving the particles away from one another and closer to the airway walls. An electric charge can be induced on the airway wall, which acts to attract the particles towards the wall. This mechanism is viewed as being a very small contributor to overall particle deposition.

4.9.1 Deposition Models

In an attempt to understand the deposition of particles in the lung the Task group [13] developed a model where the respiratory system was simplified into three regions, these are discussed in detail by Phalen [14], but he also highlights some of the weaknesses of the model, in that it assumes uniform deposition within a given region. This model has now been superseded by the model developed by the International Commission on Radiological Protection (ICRP)[15], which subdivides the respiratory system into four main regions. This model allows for age, gender, race, ventilation rate, and nature of exposure and particle size. A comprehensive overview

of this model is outlined in the COMEAP report [12], showing that particles greater than about 1μm get deposited in the *Extrathoracic* region, this deposition being enhanced by turbulent flow. Particles deposited in the *Extrathoracic* region are easily removed from the respiratory system by mucocillary action. Minimum overall deposition efficiency occurs for particles of approximately 0.5μm, while deposition efficiency within the *Bronchial and Bronchiolar* regions increases as particle size falls below about 0.1μm, there is a rapid increase in the deposition of particles in the *alveolar-intersitial* region as the particle size decreases from about 0.1μm to 0.01μm. The overall maximum deposition efficiency for particles within the respiratory system occurs for particles of about 0.01μm, with most of this deposition being in the *Bronchial, Bronchiolar* and *alveolar-intersitial* regions. In the case of particles below about 0.01μm in size, their deposition rate in the *alveolar-intersitial* region decreases, as the particles are actually small enough to enter the region and to flow back out again during exhalation. The model shows us that for particle deposition within the human respiratory system that the size ranges of particles of most interest are primarily those within 0.01μm to 10μm. It should be noted that this size range coincides quite well with the size range of particle for which we have ambient measurements. (These particle deposition size ranges as discussed above are based on a typical adult male, there would be differences in deposition rates for children and females.) These deposition models have been developed based on the controlled study of the deposition of radioisotope labelled particles, both the model predictions and experimental data for these studies [15] agree quite well. Other work on

particle deposition has been based on studies of deposition in animals, however due to anatomical differences between animals and humans, the results of these studies cannot be directly related to deposition in humans. This point is emphasised by Asgharian et al [16] and others [12]. Earlier in this chapter, it was pointed out that there are differences between the two lungs, Pityn et al [17] report on how this difference between the two lungs manifests itself with differing particle deposition between the lungs. They reported more deposition in the right lung based on a study of healthy individuals. Bennett et al [18] investigated how the deposition of particles within the human respiratory system might vary with age, they found particle deposition to be independent of age. Kim and Hu [19] report differences in particle deposition between healthy males and females, with higher deposition within females. Probably the most important reported results with respect to potential health effects from fine particles is the work of Kim and Kang [20], who studied the differences in particle deposition between healthy individuals and patients with obstructive airways disease. They found that there was a marked increase in the deposition of particles in patients with obstructive airways disease, this would help in the explanation of some of the reported adverse health effects from particulate pollution which have been covered elsewhere in this report.

The deposition of particles within the human respiratory system has also been used to the benefit of the patient, as this is the main principle of operation of inhalers used to treat patients with airway obstruction. Newman [21] has reported on the deposition of inhaled (medicinal) aerosols.

Rees et al [22] have reported on the importance of particle size in inhaled drugs, while Laube [23] has reported that anti-inflammatory agents appear to be most effective when deposited throughout the airways. Conventional inhalers produce a fine mist of drug particles propelled by a Chloroflorocarbon (CFC) propellant gas. Due to International agreements to reduce CFC gas emissions [24] into the atmosphere there has been significant efforts to design a drug delivery system which delivers drugs in particulate form to the airways which does not rely on CFC gases as a propellant agent. Leach [25] and Harrison et al [26] report on the improved deposition efficiency of new CFC free inhalers, this improved efficiency being due to the fact that the drug particle are of a smaller size to those in the conventional CFC based inhalers. The benefit in the use of the smaller drug particles, which improve the deposition efficiency is that less drug is required to be administered to the patient and it reaches areas of the lung not available to the larger particles produced by the conventional CFC based devices.

4.9.2 Particle Retention

It has been shown that particles, be they ambient or therapeutic drugs can be deposited within the human respiratory system. But if particles simply enter the system and leave they are unlikely to have any health effect, therefore the question of how long these particles are retained within the respiratory system is of the utmost importance to this study. This study is not concerned about the possible chemical interactions that might occur with the particles, but merely with the duration of time that different sized

particles reside within the human respiratory system once they have been deposited there. The COMEAP report [12] discusses that for particles that get deposited in the *Bronchial and Bronchiolar* regions that clearance of these particles is fairly rapid, with complete removal of particles within about 24 hours, although some slower clearance rates have been observed [27]. In regard to the retention of particles in the *Alveolar-intisitial* region, the convention is to talk of *half-times* of retention; this is similar to the concept of the half-life of a radioisotope. The *half-time* is basically the time it takes to remove half of the particles, which have been deposited at the particular time. Bailey et al [28] report *half-times* for particles deposited in the *Alveolar-intisitial* region ranging from 300 days to years. This should not be surprising, if one refers back to the illustration of the lungs of the former steel plant worker, one can see that there has been a build up of particles within his lungs, and obviously these particles have not been removed.

4.9.3 Health effects and Particle Retention

From the perspective of the health implications of the deposition of ambient particles within the human respiratory system, clearly the larger particles which are easily removed (filtered) in the *Extrathoracic* region are unlikely to have any major respiratory health implications. Particles which are retained in the respiratory tract, from a day to a number of days, these will be primarily particles in the size range < 0.5μm, are more likely to have the potential to cause health effects. The regions of the respiratory system which are of most interest are the *Bronchia, Bronchiolar* and *alveolar-intersitial,* as these are the regions in which particles are likely to be

retained for 24 hours or longer. Churg and Braurer [29] report that form a point of view of a study on the health effects of particulates, one should concentrate on particles with diameters < 2.5μm. Peters et al [30] also link health effects to particle size, where they claim that the ultrafine, or smaller, particles are those most associated with adverse health effects, this has also been reported on by Schwartz et al [31].

4.10 SUMMARY

This chapter has outlined the anatomy of the human respiratory system. It has looked at how particles can get deposited, and retained within the respiratory system. It has also shown that particles, which are retained for longer, are more likely to have health effects compared to particles, which are quickly removed. The particles, which are retained longest, are the smaller particles, and they are the particles, which penetrate deepest into the respiratory system. It should be remembered that the smaller ambient particles are typically produced by combustion processes. Since it has been shown that it is accepted that particles can be deposited within the respiratory system and retained there, then it is reasonable to study the possible health implications of changes in ambient particle levels. Particle composition has not been considered, nor potential interaction mechanisms, these will be covered in the discussion chapter.

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Chapter 5

EXPOSURE AND METEOROLOGICAL DATA

5.1 INTRODUCTION

This chapter discusses the history and development of the airborne particulate pollution monitoring networks in Ireland. Particular attention will be given to the network directly involved in this study. Some information on other particulate pollution measurements conducted outside of the main monitoring networks is also disused. The nature of pollution data available to this study is discussed, together with information on how the data has been compiled. An explanation is given as to how the data has been processed for use in this study. A discussion is given as to how the exposure data as available in this study compares with that used in other published studies, and conclusions as to the suitability of the data for use in population exposure studies is given.

It has already been discussed in Chapter 3 as to the role that meteorological conditions can play in the formation of pollution episodes; furthermore, meteorological parameters can themselves give rise to health effects. A detailed discussion on the meteorological data available to, and used in this study is also covered in this chapter.

5.2 MEASUREMENT OF PARTICULATE POLLUTION IN DUBLIN

Dublin is the capital city of Ireland and is also the largest population centre, as such the study of pollution levels in Dublin and the associated health effects form a major part of this study. It is fortunate that there is some evidence of pollution measurements being made in Dublin over a large part of this century, these measurements were made as parts of research projects and as such are not continuous, but they do give "picture shots" of pollution levels at various points throughout the century from which it is possible to discern trends in pollution levels.

5.2.1 Measurements of Condensation Nuclei Concentrations

Nolan and Doherty [1] report on making measurements on the concentrations of condensation nuclei, in the air in Dublin in the late 1940`s, they report that the bulk of their winter observations were in the range 40,000 to 80,000 particles per $cm^3$. They used a condensation nucleus counter, whose design and operation and calibration is described by Nolan [2]. O`Dea and O`Connor [3] have suggested a classification scheme for the degree of particulate pollution based on the concentration of condensation nuclei present in the atmosphere, using their classification, the levels recorded by Nolan and Doherty would be classified as *little* to *mean*. Nolan and Tedde [4] also made measurements of condensation nuclei at the School of Cosmic Physics for the first half of 1949, they report an average concentration of 83,000 particles per cm^3, however for the winter period their average concentration was 124,000 particles as opposed to 57,000 for

the spring period. This difference they attribute to the reduction in domestic and office heating. This winter concentration is classified as *very polluted* using the scheme of O`Dea and O`Connor. Nolan and Tedde also compare their readings with those of Boylan [5] from 1926. Boylan recorded average values for the winter period of 25,000 particles per cm^3, at Earlsford terrace, this is a factor of five times lower than the concentrations observed by Nolan and Tedde 20 years later for monitoring sites less than 1km apart. Boylan did use a slightly different type of instrument. Nolan and Tedde made measurements at both locations and found that their measurements were lower by about a factor of between 2 and 3 at the site used by Boylan, compared with the measurements obtained for the School of Cosmic Physics site. They obtained average concentrations of approximately 52,000 particles per cm^3 for this location, still twice the concentrations measured by Boylan for this location. They concluded that their measurements at the School of Cosmic Physics were being unduly affected by local sources. These early studies do give some indication as to the levels of particulate pollution, and they also illustrate the fact that scientists were interested in measuring pollution levels at that time. I do believe that the measurements of Nolan and Tedde do indicate an upward trend in particulate pollution levels compared with the levels observed in the 1920`s. Burke and Nolan [6] report an average concentration of 65,000 particles per $cm^3$ in the mid 1950`s for this Earlsford terrace site, confirming this upward trend in particulate pollution levels. Hayes [7] reports on measurements made at a number of locations in Ireland during the years 1967-69, the highest concentrations are reported for central Dublin with average concentrations

of 178,000 particles per cm^3. He also reports that at times concentrations were detected which went off the scale of the instrument. More recently Scott [8] using the same measurement techniques, made measurements at University College Dublin (Belfield) during the winter of 1979. He reported winter mean concentrations of 40,000 particles per cm^3 for what is an relatively isolated site. These winter values are about 50% higher than the autumn concentrations he obtained; Scott attributes the higher winter concentrations to the use of domestic fires for heating purposes. Scott also reports on measurements made in the city centre area with the readings often going off the scale of the measuring instrument, and with typical concentrations being 4 to 10 times higher than those measured at the Belfield site. Taking this lower scaling factor this would give a lower average concentration of 160,000 particles per cm^3 for the central city area, which is similar to the concentrations reported by Hayes. Using the O`Dea and O`Connor system gives a classification of *very polluted* for the air quality in central Dublin. The upper limit of the instrument used by Scott [8] is of the order of over 400,000 particles per cm^3, and this limit he states was exceeded on a number of occasions. It is clear that by the late 1970`s the level of airborne particulate pollution in Dublin city had become quite significant.

There does not appear to be any published data for readings of the concentrations of condensation nuclei made in Dublin city during the 1980`s, but as part of this study some readings were made for the early years of the 1990` to give some comparison. Mc Gloin [9] made measurements at

two locations in Dublin during the winter of 1990/91, this was the first winter of operation of the coal ban, and although one of the sites was away from the city centre, the average concentration was 16,000 particles per cm^3. This shows a significant reduction on the levels recorded by Hayes, and is even lower than the levels recorded by Scott, for the isolated Belfield site. The maximum concentration reported by Mc Gloin was 137,000 particles per cm^3, which was recorded at the Kevin St site which is less than 400m from the Earlsfort terrace site used by the earlier researchers and is significantly below the extremes reported by Hayes where the instrument went off scale. Again, this figure indicates the reduction in particulate pollution levels in Dublin after 1990.

Cooney [10] conducted a similar study over the winter of 1991/92, making measurements at the Kevin st site (city centre) and at a residential location. The maximum concentration for the Kevin St site was 124,000 particles per cm^3, while the average was 27,500 particles per cm^3. The residential site in Clontarf recorded a maximum concentration of 27,500 particles and a average of 8,900 particles per cm^3. These readings confirm the reduction in particle concentrations; perhaps the most marked observation is the average concentration for the residential site, which is significantly lower than the earlier readings of Scott for the Belfield site. Cooney states that on the date on which the maximum concentration was observed at the Kevin St site three of the Black Smoke monitoring stations (discussed in the next section) exceeded the 250μgm^{-3} EC limit for smoke, one of these sites being close to the Kevin St site. Richards [11] continued the

study for the winter of 1992/93 again making measurements at the Kevin St site. She reported a winter average of 18,000 particles per cm^3; this is a further reduction on the concentrations reported for this site in other studies.

5.2.2 Measurements made collecting samples on a filter system.

Leonard and Mc Verry [12] have reported on measurements of a number of atmospheric pollutants made at a site in Merrion St. in Dublin for the winter of 1938. Among the items measured was the concentration of particulate matter measured by a method described by Owens [13]. This method involved sucking air through a filter, and then evaluating the level of staining of the filter, the reading was then referred to a standard calibration curve, this method is a forerunner of the BS method described in Chapter 2. Leonard reports that this system of measurement was in use in a large number of British cities. Leonard reported that average winter particulate pollution concentrations measured in Dublin were 2.4 times greater than the summer concentrations. Measurements were also made on the amount of solid matter collected in rainfall, it is reported that although the mass collected in Dublin was similar to that of a number of major British cities, the concentration of tar present in the samples from Dublin was significantly higher than that in the British cities, Leonard attributes this to high level of domestic coal usage in Dublin. Leonard also estimated that for Dublin domestic sources emited about 3.3 times more particulate pollutants into the air compared with industrial sources. The average winter concentration of particulate matter is described as being very similar to that observed for a site at Westminister Bridge in London for the same period.

This study by Leonard et al [14] was continued into 1939, and they observed seasonal variation in particulate pollution levels, which they attributed to domestic coal burning. This paper by Leonard also looked at the relationship between respiratory mortality and particulate air pollution in Dublin; this aspect of that paper is discussed in Chapter 10. For the winter of 1940 Leonard et al [15] report that the concentrations of particulate matter were the highest recorded, this they attribute to the very cold weather and to the consequent increase in coal consumption. They give a mean smoke concentration of $820\mu gm^{-3}$ for the month of January, falling to a mean concentration of $170\mu gm^{-3}$ during the summer months. These figures may not be directly comparable with more modern measurement systems; a point emphasised by Brimblecombe [16]. Here again Leonard investigated the relationship between airborne particulate pollution and respiratory mortality, he also looked for a lag structure between exposure and mortality, this particular aspect of the work is also discussed in Chapter 10. This work of Leonard et al continued for 1941 [17], however for 1941 they report a reduction of over fifty percent in particulate pollution levels when compared with the averages for the previous three years. This reduction in pollution levels they attribute to the reduction in coal burning, which was primarily due to a shortage of supply due to the Second World War. They also report for this winter that respiratory deaths were the lowest since their studies began. The final report in this annual series was for 1942 [18], here again the reduction in pollution levels reported in the previous year had been maintained. They report that the staining of the filter in the sampler was a more "brownish" colour than those experienced in 1940, this is attributed to

the greater use of peat as a domestic source of heating.

In 1950, Leonard [19] published a brief report on the pollution levels from 1944 to 1950. In this work, he reports that pollution levels start to rise again in 1948 and 1949, as coal becomes more available. This series of work by Leonard serves to show the strong association between domestic coal usage and particulate pollution in Dublin air.

5.2.3 The development of a permanent monitoring network

In April 1963 Dublin Corporation (The Local Authority with responsibility for the Dublin County Borough area) installed its first volumetric sampling station for smoke and SO_2 at a site at the Cornmarket in Dublin city (appendix III). By the end of 1965, there were five such monitoring sites in operation [20]. In 1973, the monitoring network was again extended to give a total of twelve sites, with four of these being in the suburbs. These stations gathered daily values for smoke and SO_2 concentrations. In 1980 two further sites were added to the network, although it must be pointed out that the actual location of some of the monitoring stations changed mainly by being relocated to another building in the same area. In 1983, Dublin Corporation commissioned a report on the network [21]; this report assessed the suitability of the monitoring sites for the purpose of monitoring ambient pollution levels, and also evaluated the monitoring equipment. The report recommended the closing of some sites, the relocation of others and the addition of some new sites, together with the use of more standardised equipment. Two of the sites closed on the

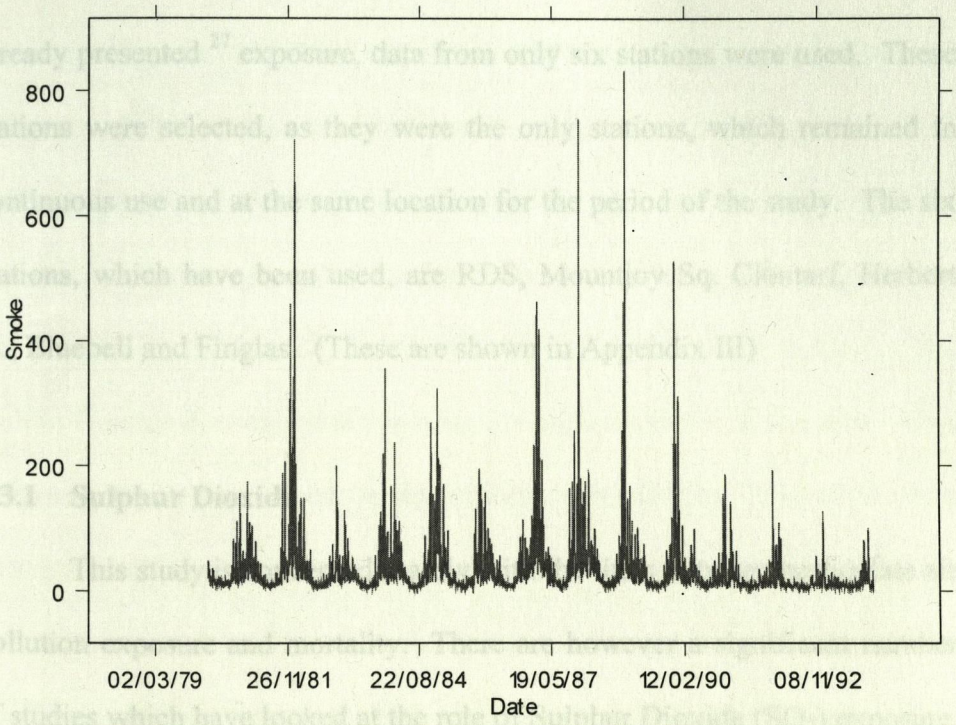
recommendation of the report were at the Cornmarket and at the Customs House, these had been in continuous use since the network had been set up in 1963, they closed at the end of March 1985. A third site was also discontinued at the same time, while two new sites started operation on the 1st April 1985. Other new monitoring sites were added to the network to give a total of 14 monitoring sites in operation in 1997. All of these sites were measuring daily 24hr averages of smoke by the BS method and SO_2. Sinclair [22] gives a detailed account of the changes to the monitoring sites in the network. Recently [23] some experimental measurements of PM_{10} have been conducted at a number of the monitoring sites. It should also be mentioned that the national Electricity Supply Board (ESB) also ran a monitoring network, primarily to monitor the output from electricity generating stations. Detailed continuous readings from this network for the period of interest in this study are not available, and so none of the data from the ESB network has been used, most of these sites are close to power stations, most of which are quite distant from Dublin.

5.3 POLLUTION EXPOSURE DATA FOR DUBLIN

Daily pollution data for smoke and SO_2 concentrations have been obtained from the Department of the Environment for each of the monitoring stations in the Dublin network, as operated by Dublin Corporation, from 1974 to 1996. The data for the 1970`s is not complete, with the identity of some of the stations being unknown. Bailey [24] reports a general decrease in both smoke and $SO_2$ levels for Dublin during the 1970`s, this he attributes to "changing fuel use, similar to trends observed in the

UK". He also mentions however, that he expects this downward trend to be reversed as more solid fuel is used in place of oil, particularly in private dwellings.

Particulate pollution levels in Dublin 1980-96 (in μg m^{-3})



Graph 5.1

McGettigan et al [25] summarises the trends in air pollution as measured by the Dublin Corporation for the decade from 1981 to 1991. They report a significant rise in smoke levels at the start of the 1980`s, and that these high levels continued until the introduction of the ban on bituminous coal [26].

For the purposes of this study the availability of mortality data is the limiting factor, and although trends in pollution levels can be studied for most of the decade, a detailed study of the links between particulate pollution and mortality can only be conducted for the period from 1980 to 1996, which is the period for which detailed daily mortality data is available. As already mentioned a number of the monitoring stations changed location, and some closed while new ones opened. For the work already presented [27] exposure, data from only six stations were used. These stations were selected, as they were the only stations, which remained in continuous use and at the same location for the period of the study. The six stations, which have been used, are RDS, Mountjoy Sq. Clontarf, Herbert St., Bluebell and Finglas. (These are shown in Appendix III)

5.3.1 Sulphur Dioxide

This study is concerned mainly with the links between particulate air pollution exposure and mortality. There are however a significant number of studies which have looked at the role of Sulphur Dioxide (SO_2) exposure. In fact, the EEC recommended safety levels for smoke and SO_2 linked the two pollutants together, this is not all that surprising since most fossil fuels contained Sulphur. In Dublin, data was available for SO_2 levels at the same monitoring stations as those used for the particulate monitoring. The SO_2 levels were measured in accordance with a method prescribed in the BS 1747 standards, these yield a 24hr average value for SO_2 concentrations. In view of the fact that this SO_2 data was available, it was decided for completeness that it should be included within the analysis of the data.

5.3.3 Dublin Exposure Data Used in this study

For the period from the 1st of April 1980 to the 31st of December 1996, there were only forty two days (0.68% of all possible days) for which no particulate pollution levels were available. When data was only missing from a single individual day, the missing value was substituted by taking a simple average of the pollution value for the two days on either side of the missing value. In 1994 there was a period of twenty eight consecutive days where no pollution measurements were made, this was due to industrial action taking place within Dublin Corporation who operate the monitoring network. Data was generated for those days with missing values, by taking the measurements for the Dublin County network, which encircles the Dublin County Borough, and applying a weighting factor to the data. This weighting factor was based on determining a correlation between the two networks over a period of years, then the daily values for the Dublin County network were multiplied by the correlation value to generate daily values for the Dublin County Borough. This technique was only applied when there were two or more consecutive days of missing data for the Dublin County Borough monitoring network. By applying this technique a data base with no missing pollution values was produced, even if no effort had been made to replace the missing values, the level of missing values was extremely small, much less than 1% of the total number of days in the study period. The same approach was applied to missing SO_2 data.

The six monitoring stations referred to in section 5.2, and which are

shown in appendix III were used to determine the exposure of the population to particulate pollution. The average of the daily particulate pollution concentrations from the six stations was calculated and this average particulate concentration was the concentration used to determine the exposure of the population. If data was not available for one of the stations on a given day, the average concentration as calculated from the data of the remaining stations was used to determine an exposure concentration for the day in question. These daily averaged particulate pollution concentration values are used in the analysis model to represent the daily exposure of the Dublin population to particulate pollution.

5.4 SUMMARY STATISTICS ON THE EXPOSURE DATA

Some summary statistics were conducted on the exposure data to look the maximum and minimum values, average values and 25 and 75 percentile values of pollution. This was done for the overall study period and for the pre and post coal ban periods. This analysis was conducted for the single smoke readings (lag 0), for running averages of smoke values, 5 day running average, lag 0-4, and a 45 day running average lag 0-44.

Summary particulate pollution data (in μgm^{-3})

Category	lag 0	lag 0-4	lag 0-44
max pre ban	883	473	108
max post ban	192	124	36
ave pre ban	35	35	35
ave post ban	13	13	13
overall ave	27	27	27
Interquartile range			
pre ban	28	30	31
post ban	8	7	8
overall	21	23	24

Table 5.1

The summary data in the above table 5.1 shows the extent to which pollution levels rose over the period and also the magnitude of the changes brought about by the ban on bituminous coal sales. The maximum single day value in the pre ban period is over 3 times greater that the EEC recommended maximum level, and this particular value is averaged over 6 monitoring stations, whereas the EEC limit refers to a single monitoring station. The improvement in air quality brought about by the coal ban saw maximum values fall by 77% for the 1 day reading, 74% for the 5 day moving average, and 67% for the 45 day moving average, when the pre and post ban periods are compared. When pre and post ban, average values were considered they show a 63% reduction in particulate pollution levels as a consequence of the ban. What is also of interest is that the intraquartile

ranges are very similar for the 1 day, 5 day and 45 day moving averages of pollution exposure.

These figures clearly show that the ban on the marketing and sale of bituminous coal lead to a significant reduction in particulate pollution levels in Dublin. This reduction was not just confined to extremes in pollution levels, but was also reflected in the overall averaged pollution levels, which showed a significant reduction following the introduction of the ban.

5.4.1 Summary Of SO_2 Data

As mentioned already SO_2 was not of prime concern within this study, but because of the availability of the SO_2 data it was decided that this data should also be utilised in the analysis.

Summary SO_2 data (in μgm^{-3})

Category	Lag 0
max pre ban	262
max post ban	104
ave pre ban	40
ave post ban	23
overall ave	34

Table 5.2

SO_2 Interquartile ranges (in μgm^{-3})

pre ban 25%	26.7
pre ban 75%	50.0
post ban 25%	16.5
post ban 75%	26.5

Table 5.3

5.4.2 Winter Time Pollution and Annual Pollution

It was decided that since Ireland was viewed as having the classic winter time pollution, that the difference between winter and summer air pollution levels should be investigated. For the purpose of this, winter was taken as the 4 months, from November through to February inclusive, while this was compared with the remaining 8 months.

Summary winter/rest of year pollution (in $\mu g\ m^{-3}$)

	Winter average	rest of year average	ratio
pre ban	62.8	22.5	2.8
post ban	19	11	1.7
overall	46.4	18.2	2.5

Table 5.4

The results presented in table 5.2 do indeed show the huge variation between winter time pollution levels in Dublin, and levels for the remainder of the year. This is most marked in the pre coal ban period, where winter levels averaged at 62.6 μgm^{-3}, with the remainder of the year giving an

average concentration of 22.5 μgm^{-3}. This also shows that on average winter time concentrations of particulate pollution were 2.8 times higher than levels for the remainder of the year. When the coal ban is considered it is seen to have reduced winter time particulate pollution levels by 70%, levels for the remainder of the year are seen to fall by 50%. This clearly shows that Ireland did experience the classic winter time air pollution, with winter pollution levels significantly higher than those for the remainder of the year. It also shows that the coal ban reduced both winter, and remainder of the year average pollution levels, with the greatest reduction in the winter time pollution levels. It is worth noting that these results are in good agreement with those of Leonard [12], who observed that winter time pollution levels were 2.4 times higher than summer time levels for Dublin, he was referring to 1940. Leonard et al [17] also reported that particulate pollution levels were seen to fall by over fifty percent due to the lack of coal supplies, this reduction in pollution levels is consistent with the reductions observed following the 1990 coal ban.

5.5 EPIDEMIOLOGICAL CONSIDERATIONS

An issue, which is often raised in relation to epidemiological studies involving air pollution, is one of calculation of personal exposure. In this particular study, it is obvious that to issue every person with a personal pollution monitor would not be feasible. How is it possible to relate the pollution measurements made at a series of monitoring sites to individual exposure? There is no real correct answer to this question, but some studies [28,29,] have shown a significant correlation between indoor particulate

pollution levels and ambient outdoor levels. Jansen et al. [30] report a reasonably high correlation between personal and ambient PM_{10} exposure within individuals, saying that this "provides support for the use of ambient PM_{10} concentrations as a measure of exposure in epidemiologic studies linking day-to-day variation in particulate matter air pollution to the day-to-day variation in health endpoints such as mortality...". Even if ambient particulate pollution levels do not represent a particular individual, it is reasonable to assume that the changes in personal exposure should follow the changes in ambient levels. Katsouyanni et al [31] has addressed this same question in relation to a study in a number of European cities. It must be noted that the "day" is actually the unit of measurement in this study, not the person, so one has values for a number of parameters for each day. When the changes in these parameters are modelled together, while controlling for possible confounding, it is the correlation's of the population as a whole with changes in pollution levels that is of interest, and not the individual. It is reasonable to use the value of particulate averaged over a number of monitoring sites to represent the average exposure, as averaged over the whole population. An advantage in this type of study is that the population acts as its own control, in that the risk factors for mortality, such as the level of cigarette smoking, cholesterol levels, alcohol consumption etc are unlikely to change from day to day. Therefore if there are changes in day to day mortality, and these changes correlate closely with pollution events, then since the population have not changed, and since the risk factors will not have changes in such a short term, the use of an entire population group in such a study is justified. The COMEAP [32] group have addresses these

issues, they report that the results from this type of study have been consistent from studies on different continents. Therefore the use of daily averaged pollution data from a number of monitoring sites, and the use of a complete population group in such a times series study is consistent with current research trends.

5.6 METEOROLOGICAL DATA

Weather conditions have long been known to influence the death rate, and in particular extremes of hot or cold temperatures appear to increase mortality rates [33]. In a number of locations, the mortality rate is shown to have a strong seasonality relationship [34,35]. In a number of European countries, studies have shown that there can be a significant difference in the mortality rate, types of mortality, between the northern, and southern parts of the country [36,37] . Eng and Mercer [38] attribute the higher mortality rates to the Northern, or colder parts of these countries. Quite clearly if one is studying the relationships between particulate air pollution and mortality then one must also take into account potential confounding items such as temperature and humidity, and control for these items. In the APHEA [39] study, the authors clearly show that one must control for changes in temperature and humidity. In chapter 3 it was shown that cold winter weather associated with a high pressure, system was also conducive to pollution formation in Ireland. Cold temperatures and particulate pollution levels are likely to be highly correlated. In trying to investigate the relationships between particulate pollution and mortality, one must be sure that our mortality is not attributable to the cold temperature,

but to the pollution. It is therefore vitally important that accurate, reliable meteorological data is available to this study.

The Irish Meteorological Service (Met Eireann), operate a series of 15 synoptic weather stations across the country. Each of these stations is manned 24hrs a day 365 days a year. Detailed meteorological data is available on an hourly basis for each of these stations. For the purpose of this study daily mean temperature, maximum temperature, average temperature and average relative humidity values were obtained from Met Eireann. The data was obtained for the synoptic weather station at Dublin Airport; this is the nearest weather station to the study area. Daily data for these meteorological parameters is complete for all of the days in the study period; there is no missing data. This data was supplied in digital format, and the daily values for each parameter were included into the overall database. (The temperature values are in degrees Celsius)

It should be noted that all the exposure data is based on measurements made in the time interval from midnight to the following midnight.

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Chapter 6

HEALTH EFFECTS DATA

6.1 INTRODUCTION

This chapter outlines the health data available to this study, and discusses how this data has been acquired, and processed for the needs of the study. Summary information is given on the total amount of data available, the aspects, which have been used, and the strengths and limitations of the data are discussed. The health data available to this study is compared with that used in other published studies.

6.2 DATA USED

Due to lack of availability of complete hospital admission records for Dublin for most of the period under investigation 1980-1996, it was decided that this study would only consider mortality records. The big advantage of using mortality records is that there is a comprehensive complete set of information available. It is a requirement by law [1] that each death in Ireland, must be recorded and registered. Permission was granted by the Minister for Health, allowing access to the mortality data for Ireland for the time period under investigation. An undertaking was given that there would be no follow up on any individual cases, and that the anonymity of all deceased persons would be upheld. Every death is registered in the county registrar's district where the death occurred. The information provided on the death registration certificate, gives the age of the deceased, the cause of

death, county of residence of deceased, county of death of deceased, sex, marital status, date of death, ancillary information as to occupation, whether death was at home, in hospital or other location is also provided.

Each death must be registered within one calendar year of the date of occurrence of the death. The deaths from all parts of the country are collated and compiled by the Central statistics Office (CSO). The deaths records are computerised into individual files for each calendar year based on deaths which have occurred within that calendar year. Because of the fact that a death can be registered up to a year after its actual occurrence, and because the CSO wish to ensure that they have a complete set of records, the complete file of deaths for any given calendar year is almost two years behind, that is 1996 mortality was only available towards the end of 1998.

6.3 MORTALITY DATA

The complete files of mortality data were obtained from the CSO office for each year from 1980 to 1996. This data was in computerised or electronic form. In order to use the mortality data extensive sorting and selecting of the data files was required. Over the period of time in question, there were a total of 546,607 deaths recorded in the state. For each individual death, there was a complete record of all the necessary information relating to that death. These records were in ASCII format, consisting basically of a large array of numbers, each line of the file referring to a specific individuals death.

6.3.1 Selection criteria for mortality data

Since Dublin County Borough was the particular geographical region under consideration, it was decided that only deaths of those resident within the area would be considered. This area was chosen as it had experienced high particulate pollution levels at various times [2], and since the bituminous coal ban [3] applied to this area. If the greater Dublin area had been chosen, there were large parts of that area to which the coal ban was not applicable, and thus the possibility of studying the effect of the ban would have been lost. The cause of death was of major consideration; it was decided to only consider non-accidental deaths. All deaths were encoded with a cause of death; the coding used was in accordance with the International Cause of Death, 9th revision [4] (ICD-9). All deaths where the ICD-9 cause of death was < 800, which corresponds to non-accidental deaths were considered. It was further decided to select deaths by the cause of death, where these causes of death were divided into subgroups. The causes of death were divided into three categories, total deaths (all ICD-9 <800), cardiovascular deaths (ICD-9, 390-459 inclusive), and respiratory deaths (ICD-9, 460-519 inclusive).

It was also decided to subdivide the mortality data into age groups, the group is chosen were ages 0-64, 65-74 and 75 and over. Deaths by each of the ICD-9 groups listed were also subdivided by the age groups. Other studies have also split the population into age groups [5,6] in an attempt to identify which subgroup of the population is most at risk to increases in particulate pollution levels.

6.3.2 Selection of mortality data

All the mortality records for the whole country were obtained from the Central Statistics Office; this data was in electronic form. The SAS [7] computer system was used for the management of the database. For each day (date), the database was interrogated using a SAS program to select out all records, which met the following criteria;

Dublin County Borough address

Cause of death (ICD-9) < 800,

all of the records meeting this criteria were then read into an interim file, then they were summarised by date of death, age category and cause of death, the final output file for each year consisted of 365/(6) records, one for each day of that calendar year. There were a total of 11 columns in each output file consisting of;

date of death

total deaths

card/vas deaths age 0-64

card/vas deaths age 65-74

card/vas deaths age 75+

respiratory deaths age 0-64

respiratory deaths age 65-74

respiratory deaths age 75+

others age 0-64

others age 65-74

others age 75.

A summary of the notations used in this work is presented in appendix IV.

The outputs from the SAS program were saved as text files. These text files were then processed in Excel [8] to produce the final database, which was used for the analysis. It should be noted that the original CSO mortality files were encoded differently from year to year, with different address codes being used in one year, and with a one digit code being used for month of death in some other years, this necessitated a few versions of the SAS program to select the required data from the overall yearly CSO files. The SAS program used to select and summarise the mortality data is shown in appendix V.

6.4 SUMMARY OF MORTALITY DATA

There was a total of 6119 days in the study. The total number of deaths for the Dublin County Borough was 80,307, with an average of 13.12 deaths per day. The maximum daily number of deaths was 39 and the minimum was 1. The median was 13. Over the whole period, there were 11,564 respiratory deaths (14.4% of total), cardiovascular deaths accounted for 37,035 deaths (46.1%). When the age groups were considered 18,627 deaths (23.2%) occurred in the 0-64 age group, 21,564 (26.9%) in the 65-74 age group, and 40,116 (49.9%) in the 75 + age group. With an average number of 13 deaths per day, this is a suitable number to conduct a Poisson analysis. Quite clearly the greater the number of deaths, the more confidence one can have in the outcome of any modelling of the data. It is interesting to note that the highest daily number of deaths (three times the daily average) occurred on the 14th January 1982, in the middle of the period studied by Kelly and Clancy [2].

6.5 POPULATION DATA

The Irish government conducts a census of population every five years, this census being undertaken by the Central Statistics office. The census traditionally takes place on a Sunday during the month of April in the year in question. There should have been a census in 1976, but none was conducted, a smaller scale census was conducted on the 1st April 1979 [9]. A census was conducted on the 5th April 1981 [10], which was back to the normal scheduled five yearly interval. A census was conducted on the 13th April 1986 [11], then again on the 21st April 1991 [12], and finally on the 28th April 1996 [13]. From the point of view of this study, changes in the day to day population are likely to be quite small, and so they should not have any major impact when one is looking at day to day variations in mortality as a function of particulate pollution levels. It has already been pointed out that it was decided to investigate the effectiveness of the ban on bituminous coal [3], this being the case, one would be comparing the period from 1980 to September 1990, with that from September 1990 to December 1996, changes in the population between these two time periods could easily produce misleading estimate for the effect of the ban. The following table shows the population for Dublin County Borough for each of the census years.

Population of Dublin County Borough

Year	Population
1979	544,586
1981	525,882
1986	502, 749
1991	478,389
1996	481,854

Table 6.1

These figures clearly show that there is a significant change occurring in the population of Dublin County Borough, with a general downward trend in the population, and with only a slight rise in the latter years. For the period of time of most interest that is from 1986 to 1991 (the period where the coal ban was introduced) there is a 4.7% drop in the population. The CSO were contacted to see if there was any available population data for years between census years, but no such data exists for Dublin County Borough. They advised that the best estimate was to linearly interpolate between census points, however for the purposes of this study it was felt that this might not give a reliable estimate of the population. It was decided to investigate the population by age group to see if this would provide more explanation of the population changes between census years. The following table 6.2 shows the population in Dublin County Borough by age groups, at the various census points.

Population of Dublin County Borough by age groups

Census	age 0-14	age 30 +	age 40 +	age 65+	age 75+
1979	139,096	245,486	188,641	57,567	20,400
1981	125,696	240,587	185,594	58,537	21,050
1986	109,884	237,893	179,765	58,408	22,441
1991	94,883	241,479	179,980	61,335	24,540
1996	88,031	252,808	182,660	62,934	25,404

Table 6.2

The information in this table clearly shows that most of the fall in the population of Dublin County Borough was in the younger age group, and that if one concentrates on the older age groups i.e. from age 30 upwards, the changes in the population are quite small, and in fact this age group shows a slight population rise over the period of the introduction of the coal ban. It was decided that the 30+ age group would be considered in the analysis of the effect of the coal ban. Table 6.2 also shows that older population groups, in particular the 75+ age group show an increase over the whole time period, this is linked to increased life expectancy. It should be noted that the most noticeable increase in the 75+ age groups occurs after the introduction of the coal ban.

6.6 SUMMARY OF MORTALITY DATA PRE AND POST INTRODUCTION OF COAL BAN

The following table 6.3 presents a summary of the mortality data for the periods before and after the introduction of the coal ban. The daily average and the maximum values are presented for each category for the total time period, and for the pre and post ban periods.

Comparison of mortality pre and post coal ban and overall

	All mort	All mort30	All resp30	All card30	All 6574	All 75
max all	39	38	13	18	13	21
max pre ban	39	38	13	18	13	21
max post	30	29	9	16	12	18
ave all	13.12	12.83	1.87	6.03	3.52	6.55
ave pre	13.26	12.96	1.95	6.24	3.63	6.36
ave post	12.89	12.61	1.75	5.69	3.34	6.86

Table 6.3

What is remarkable about all of the information provided in table 6.3 is that all of the maximum daily deaths in each of the categories investigated occurred in the pre coal ban period, furthermore the average daily deaths for each category investigated is higher in the pre ban period, with the notable exception of the average daily deaths for the 75+ age group. In relation to this age group, in view of the fact that the 75+ population has risen since the period of the introduction of the coal ban (table 6.2), it is quite reasonable to expect that the average daily number of deaths for this age group should also rise.

In the previous chapter, the effect of the coal ban on particulate pollution levels was discussed. From the information presented in this chapter in appears that daily mortality has also decreased since the introduction of the coal ban. Whether these two items are linked, or not, is tested using a regression modelling technique, and the results of this analysis are presented in chapter 9.

6.7 LIMITATIONS OF HEALTH EFFECTS DATA

The major limitation of the health effects data is that only the data that is available to the study can be used, clearly it would be nice to have access to more data, but if the data does not exist, one has to make the best use of the available data. It has already been explained that reliable morbidity data does not exist for the Dublin County Borough for the period from 1980 to 1996. Therefore, it has not been possible to study the links between morbidity and particulate pollution levels in Dublin. A factor

which falls outside the scope of this study is the classification of death, there is the possibility of misclassification of deaths, i.e. that a death from cardiovascular disease might be attributed to respiratory disease, or visa versa, but one has to assume that over a 17 year period as covered in this study that such mis-classifications (if they occur) will average one another out. Even if there is evidence of a systematic mis-classification of deaths, this will act to move the dose response relationships to the left, or to the right, but the slope of the dose response relationship should remain unaltered by such systematic mis-classification.

One health factor, which would have been desirable to include into the analysis model, was the incidence of influenza, and to control for its presence. Unfortunately in Ireland there is no record of influenza epidemics for the period in question, furthermore there is no policy in place for routine testing for the presence of the influenza virus, so it was not possible to include the presence of influenza into the analysis in this study.

Another aspect, which would have been of interest to investigate, was if any particular socio-economic group was more prone to adverse health effects from exposure to particulate pollution compared to any other group. It was felt that the information on the socio-economic group of the deceased was unreliable for the purposes of such a study. There is an apparent tendency that people are often recorded as being from a higher socio-economic group that what they should be, it was decided that this aspect of particulate pollution exposure effects linked to socio-economic

class would not be investigated in this study.

The health effects data used in this study has focused on using only the most reliable aspects of the available data, namely date of death, cause of death, and age at death.

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10) Census 81. Vol. 2, Central Statistics Office. Government Publications 1984.

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12) Census 91. Vol. 2, Central Statistics Office. Government

Publications 1994

13) Census 96. Vol. 2, Central Statistics Office. Government Publications 1997.

Chapter 7

METHODOLOGY OF DATA ANALYSIS

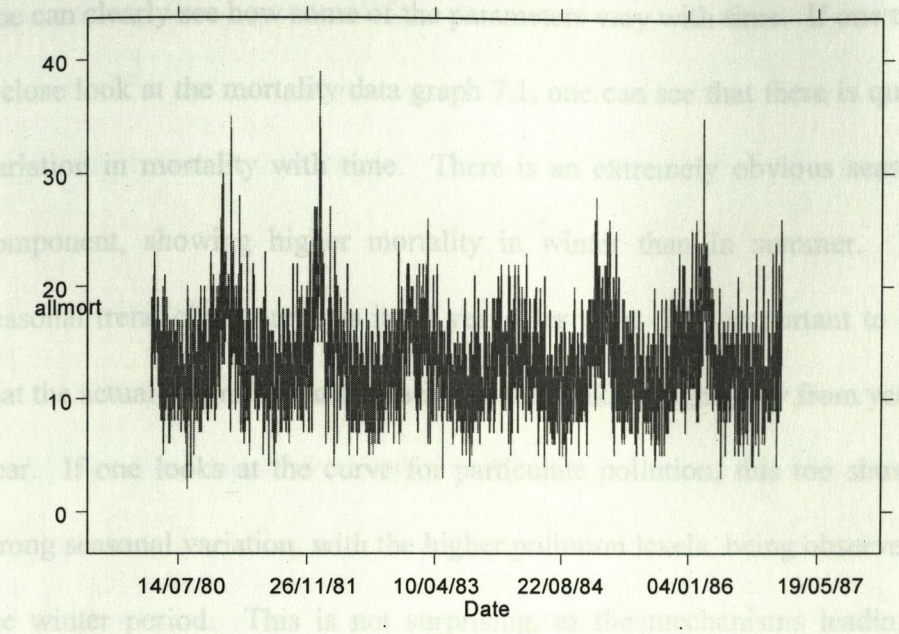
7.1 INTRODUCTION

The objective of this study is to investigate if there are any potentially causal relationships between incidences of particulate air pollution in Dublin and Mortality. To conduct such an investigation it is necessary to use various analysis techniques to study the mortality, pollution and meteorology data, as well as the links that exist between these different data sets. There have been a significant number of studies in recent years, which have sought to identify links between pollutant exposure and mortality [1,2,3,4,5], and from these studies, a methodology of analysis has evolved for use with such data sets. It is proposed, to conduct a similar type of analysis on the data in this study. This chapter outlines the analysis techniques, which it is proposed to use to analyse the data in this study.

7.2 TIME SERIES ANALYSIS

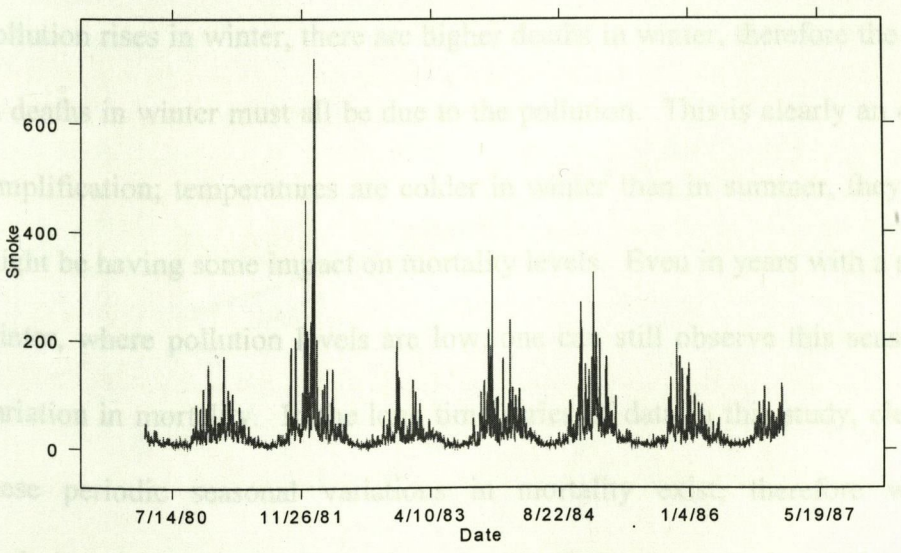
The data in this study, is what is known as time series data, basically one has data for mortality, pollution parameters and meteorological parameters on a day by day basis over a long time period. Effectively time is on the X-axis, while the other parameters are on the Y-axis.

Section of Mortality data plotted against time



Graph. 7.1

Section of Particulate Pollution data plotted against time



Graph 7.2

Graphs 7.1 and 7.2 each show a section of the data used in this study one can clearly see how some of the parameters vary with time. If one takes a close look at the mortality data graph 7.1, one can see that there is quite a variation in mortality with time. There is an extremely obvious seasonal component, showing higher mortality in winter than in summer. This seasonal trend clearly repeats itself year after year. It is important to note that the actual magnitude and location of the peaks/troughs vary from year to year. If one looks at the curve for particulate pollution, this too shows a strong seasonal variation, with the higher pollution levels, being observed in the winter period. This is not surprising, as the mechanisms leading to particulate pollution formation in the Irish context, have already been discussed in Chapter 3.

At a first look at the above graph, one would be inclined to think that pollution rises in winter, there are higher deaths in winter, therefore the rise in deaths in winter must all be due to the pollution. This is clearly an over simplification; temperatures are colder in winter than in summer, they too might be having some impact on mortality levels. Even in years with a mild winter, where pollution levels are low, one can still observe this seasonal variation in mortality. In the long time series of data in this study, clearly these periodic seasonal variations in mortality exist, therefore when analysing the data one must take account of these seasonal variations or trends in the data. Such seasonal trends are quite common in biomedical time series research [6]. With such a long time series, such as the one in this study, the population size can change dramatically over the study period.

One might observe an upward (or downward) trend in mortality over the study period. It is important that such trends are controlled when analysing the data. The methods, which should be used to control such confounders are discussed later in this chapter.

7.3 MODELLING

The basic principle in time series analysis is that one "fits" a mathematical model or formula to the data. Such a model can range from a simple linear relationship to quite complex mathematical formulations. The basic idea is that the model is a close approximation to the actual data. In this study, the data one wishes to model is daily mortality. Consider the data in the following graph, this data can be modelled by a straight line (linear relationship).

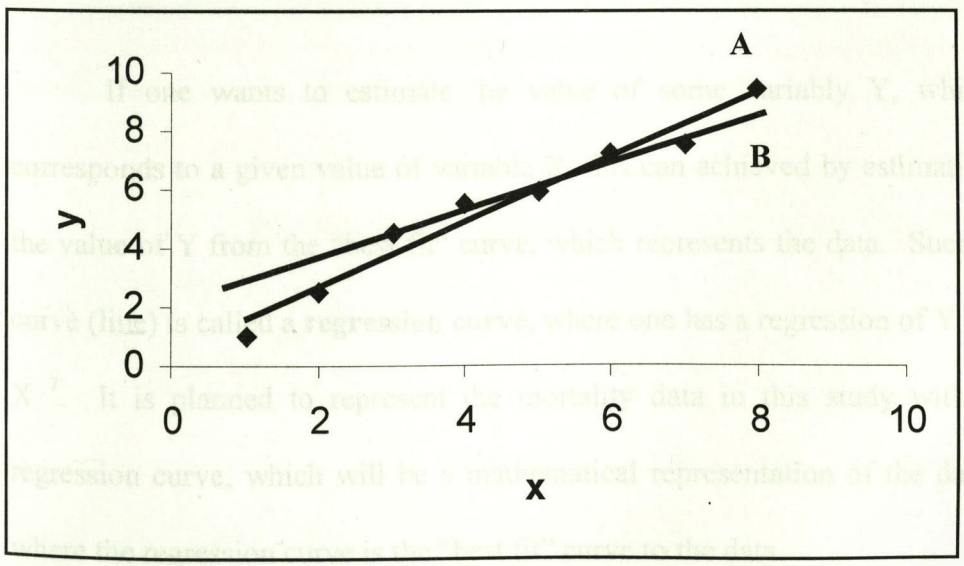


Figure 7.1

This data can be represented by the mathematical formula;

$$y = mx + c \qquad \textbf{eqt. 7.1}$$

This is just the simple equation for a straight line. There are *two* straight lines shown on this graph, which one is most representative of the data? To answer this question one needs some process by which the "best fit" line can be evaluated. One approach is to minimise the distance from all the data points to the line; this is called a *least squares* fit. If e_i is the absolute distance from a point i to the line, then the line for which Σe_i^2 is a minimum, will be the "best fit" line for the data. The difference of a data point from the model chosen to represent the data, can be represented by e_i , where e_i is known as the *residual* . In general when one fits a model to a set of data one is trying to minimise the residuals within the model, and also the sum of the square of the residuals, this will be true whether the model is linear or of a more complex nature.

If one wants to estimate the value of some variably Y, which corresponds to a given value of variable X, this can achieved by estimating the value of Y from the "best fit" curve, which represents the data. Such a curve (line) is called a **regression curve,** where one has a regression of Y on X [7]. It is planned to represent the mortality data in this study with a regression curve, which will be a mathematical representation of the data, where the regression curve is the "best fit" curve to the data.

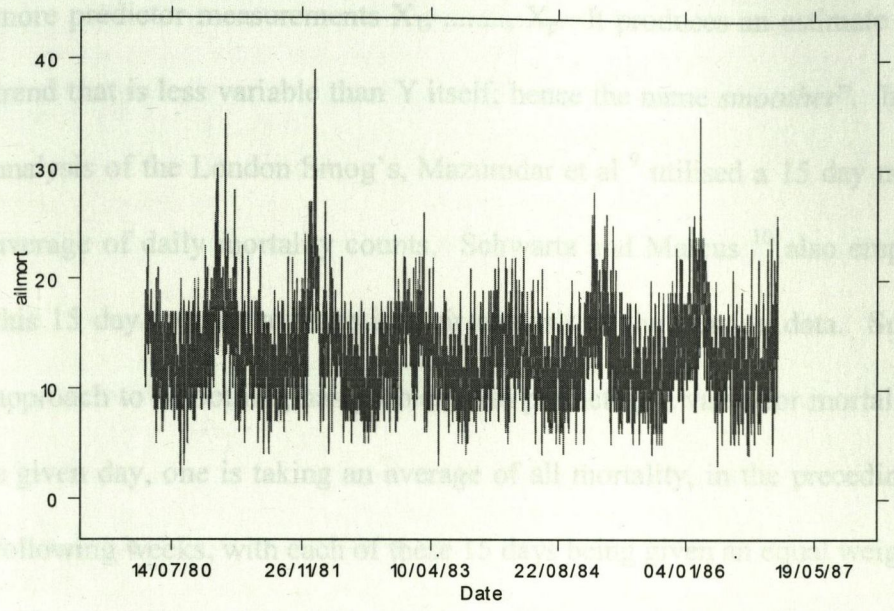
7.3.1 Smoothing

The variation in daily mortality that exists in this data set, has already been shown in graph 7.1. In attempting to fit a mathematical model to this data, it is common to apply some kind of *smoothing* to the data. This process of smoothing, is often used to eliminate unwanted fluctuations in Time Series data [7]. Items such as extreme values (of daily mortality) can sometimes have an undue influence when one is analysing data, smoothing helps to reduce such effects of extreme values. The most common type of *smoothing* is a moving average; this is where the value of some parameter is estimated as follows;

$$Y_i \text{`} = \Sigma(Y_{i-n}, Y_{i+n}) / 2n + 1 \qquad \textbf{eqt. 7.2}$$

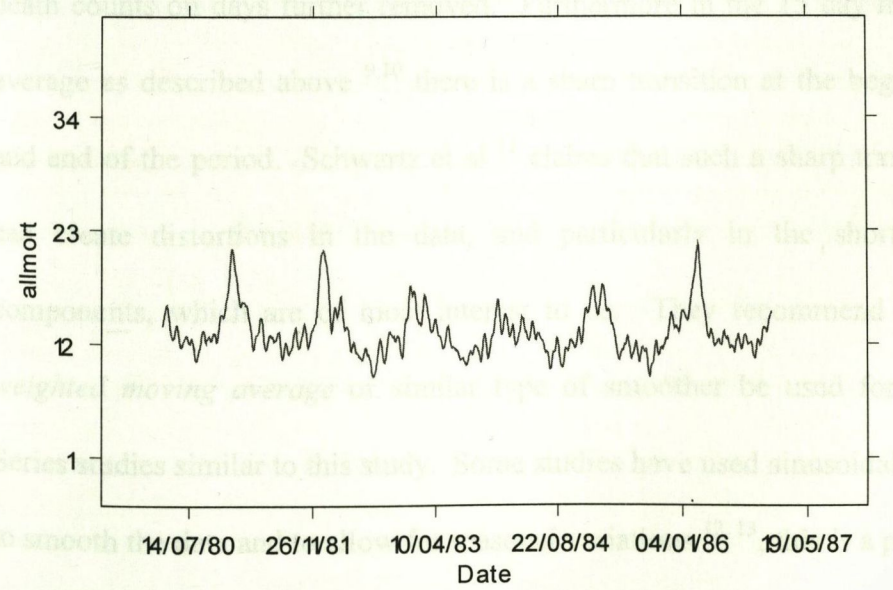
Where Y_i' is the expected value of Y, and it is the arithmetic mean of the n values on either side of Y_i. The following diagrams show a set of data and the smoothed version of the same data obtained by applying a moving average to the data.

Mortality plotted against time



Graph 7.3

Smoothed plot of mortality against time



Graph. 7.4

Hastie and Tibshirani [8] describe a smoother as "a tool for summarising the trend of a response measurement Y as a function of one or more predictor measurements X_1, ..., X_p. It produces an estimate of the trend that is less variable than Y itself; hence the name *smoother*". In their analysis of the London Smog's, Mazumdar et al [9] utilised a 15 day moving average of daily mortality counts. Schwartz and Marcus [10] also employed this 15 day moving average in their analysis of the London data. Such an approach to smoothing has problems, in predicting a value for mortality for a given day, one is taking an average of all mortality, in the preceding and following weeks, with each of these 15 days being given an equal weighting, while mortality outside this period is considered to have no bearing and is given a weighting of zero. From a common sense point of view, it would expected that mortality counts on a given day should be more related to death counts on the days close to the day in question, and less related to death counts on days further removed. Furthermore in the 15 day moving average as described above [9,10] there is a sharp transition at the beginning and end of the period. Schwartz et al [11] claims that such a sharp transition can create distortions in the data, and particularly in the short term components, which are of most interest to us. They recommend that a *weighted moving average* or similar type of smoother be used for Time Series studies similar to this study. Some studies have used sinusoidal terms to smooth the data and to allow for seasonal variations [12, 13], this is a process known as parametric smoothing. The potential problem of this approach is that it assumes that a seasonal peak is the same each year, and that it occurs at the same time each year. These assumptions render the application of

sinusoidal smoothing to this data set as being inappropriate.

An alternative approach is to use *non-parametric* smoothing; this is where a process of weighted moving averages as described above [11] is applied to the data. Such an approach estimates a value of Y at X_i as that predicted by a weighted regression using only points in the neighbourhood of X_i, one of the most common of such locally weighted smoothers is a *loess* smooth, and is described by Hastie and Tibshirani [8].

7.3.2 Smoothing Intervals

Another aspect in relation to the smoothing of the data is the choice of the size of the interval, which should be used. There is no correct answer to this question in that the size of interval may differ from one data set to another. It is proposed to test a number of different intervals, the one which produces the "best fit" for this data set will be used. If a wide interval is used this can give rise to a very smooth curve, but this in turn can lead to low variance, and possible bias if the data is over smoothed. If on the other hand the interval is small, it can give rise to a very jumpy curve, with high variance and low bias. Therefore, it is important that a number of experiments are conducted on the data using different intervals, until a suitable interval is identified. Schwartz [14] recommends that the interval should be chosen so that it gives the lowest Aikaike Information Criterion (AIC) [15], while not resulting in over correction. Over correction is identifiable by negative auto correlation in the residuals and a jumpy or bumpy curve. Having selected the interval to apply to the data, there are still

a number of other aspects, which have to be considered.

Schwartz et al [13] warn about over filtering or smoothing, they state that "by removing shorter and shorter wavelength components from the data we are effectively reducing the sample size, since less and less variation is kept in the data." They go on to say that " too much filtering risks throwing away precisely those patterns of exposure whose effects we wish to examine". Smoothing of the data is not the complete solution; the appropriate smoothing for the particular data set in question is what is required. A knowledge of the data can be an advantage in this regard.

7.4 MODEL CHOICE

The data in this study is basically daily counts of mortality. This therefore can only have positive values. As seen in Chapter 6 the average daily number of deaths is 13. These would suggest that the data is best modelled as Poisson data. Schwartz et al [11] discuss the suitability of the use of a Poisson model for such time series data. They recommend that the controlling for potential confounders, such as seasonal effects be conducted within the model itself. This approach can be achieved by the use of a Generalized Additive Model (GAM) [8]. These GAM models have an advantage in that if the relationship say between temperature and mortality is unknown, parameters like temperature, humidity etc. can be treated as continuous variables, and represented in the model by a non-parametric smoothing similar to that discussed for the seasonal component. Schwartz et al [11] also show that the Poisson Regression model is a Relative Risk

model, in that if the population were to double, and if all other risk factors remained the same, the number of increased cases due to air pollution would also double. They give the following equation for the expected number of deaths on a given day E(Y);

$$\textbf{Log (E(Y))} = \beta_0 + \beta_1 X_1 + \ldots \beta_p X_p \qquad \textbf{eqt. 7.3}$$

where X_1.....X_p are the predictors of daily counts of mortality, and β_1.....β_p are the regression coefficients for those predictors. Schwartz (12) and Kinney et al (16) have shown that even if one models mortality counts as Gaussian that the outcomes are very similar to those obtained if a Poisson model were used.

7.4.1 Robustness

In Time Series studies, one is often concerned about the effects that extremes in the data can produce when one is trying to analyse the data. Such extreme values, or outliers, can also make it difficult to produce a smooth regression. One approach which is commonly used is to apply what is known as a *Robust* component in the regression, this acts to identify extremes in the data and to apply smoothers to these extreme values [17] thus reducing their influence on the overall model.

7.5 CONFOUNDING

In this type of time series study there is always the possibility of confounding, if one is interested in the links between particulate air pollution and mortality, there is always the risk that one may attribute excess deaths to pollution when in fact they may be related to weather conditions. Weather conditions, since they can give rise to excess deaths must be treated as a possible confounder in this study. The seasonal variability in mortality is another possible confounder and it too has to be accounted for in the modelling of the data. Although this study is primarily interested in particulate pollution, data on Sulphur dioxide (SO_2) levels is also available and they too will have to be considered in the analysis. There have been a number of studies, which have shown a high correlation between particulates and SO_2, one must consider the role of SO_2 when constructing the model. In the construction of a model, if there is doubt as to whether explanatory power should be attributed to air pollution or a confounder it should be attributed to the confounder. This kind of conservative approach means that any effect attributed to pollution will be on the lower side, but it also means that if any effect is identified one can be confident that it is a real effect and not some artefact. The COMEAP report [18] endorses such an approach to the modelling of confounders. This highlights the fact that one should have an intuitive feeling for the data and the possible interactions between components when developing the model. Ultimately only confounders which fluctuate on a day to day basis, in a manner correlated with air pollution have to be considered in the model, items such as smoking, alcohol consumption and diet do not vary greatly from day to day,

and therefore do not have to be included in this type of model.

7.6 LAG STRUCTURES

From a knowledge of the data in this study is unlikely that mortality on a given day is associated with pollution, or temperature or humidity, solely on that day. There is likely to be some contribution from these parameters on preceding days as well as the day of death. Since one is interested in the effect of particulate air pollution, how many days of pollution, prior to the day of death should be considered? Having chosen the number of days, should one take a simple running average of these days, giving them all the same weighting? Giving the same weight to all days, (a simple running average) might work well with some data sets, but one would need to be able to consider other possibilities as well. Schwartz and co-workers [11,14,19] suggest the use of polynomial distributed lag models to model the lag effects. The use of such models also help to identify the lag structure, providing information on the number of days that should be considered in the lag model.

7.7 SUMMARY

The analysis techniques which are used to study the data set will follow the methods outlined within this chapter. The data will be modelled using a GAM regression model, with non-parametric smoothing for trend and season included within the model. The data will be treated as Poisson data, with a robust function included to account for outliers. Control of possible confounding parameters will be included within the model, with a

conservative approach, to ensure that any possible effects of air pollution are not over estimated. The modelling of the data will be conducted in the Splus© [20] statistical computer package. This package contains all the necessary statistical tools as outlined above. A step by step approach will be taken to the development of the model, firstly with the controlling for trend and season, and then by gradually adding in the other components, one at a time. Each step and the rationale behind it will be fully explained in the model development chapter, which follows.

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Chapter 8

DEVELOPMENT OF TIME SERIES ANALYSIS MODEL

8.1 INTRODUCTION

This chapter outlines how a model was developed for the analysis of the data within this study. The main objective in the development of the model is to ensure that the model controls for all possible confounders, that is those confounders which may be correlated with pollution. It has already been mentioned that items such as smoking habits of the community as a whole are unlikely to change much from day to day, so the confounders which are of most concern are those which are most likely to vary closely with particulate pollution, such items are meteorological parameters, and possible the day of the week effects which may affect pollution patterns. Having controlled for such possible confounders one can have a reasonably high level of confidence in the estimated effects as produced in the analysis. The development of the analysis model, and the analysis of the data has been conducted in the SPlus[1] statistical computer package. A brief summary of some of the SPlus commands used in the development of the model and in the data analyses are presented in appendix VI.

8.2 CONTROLLING FOR CONFOUNDERS

The following section outlines how each of the potential confounders were controlled for in the development of this analysis model.

8.2.1 Long term time trend

In a study of this nature where there can be changes, which occur over a long time period, it is important that these changes be controlled for in the model. Changes in life expectancy, changes in the overall lifestyle of the population, which may be due to increased wealth etc, these can all have a bearing on the potential effects of exposure to particulate pollution. There may be long term changes in smoking patterns; all of these can confound the outcome of a study like this. Other long term time trends in the data would be seasonal variations, it has already been shown that winter is colder than summer, and that particulate pollution event are more likely in winter in an Irish context, so these seasonal variations must be taken into account. In Chapter 5 it was shown that extremes of temperature can lead to increased mortality [2], so the model has to allow for these seasonal temperature variations. As has been already explained in chapter 7 a smoothing function can be fitted to the "date" or trend, as this is a variable which increments day by day over the whole study period.

An initial *Generalised Additive Model* (GAM) [3] was fitted to the data where total mortality was regressed against "Date". A loess smoothing function was applied to the "Date", with the span (the window of data, or number of days) being varied. The objective of this approach, as outlined in Chapter 7, is to fit a smoothing function to the data that "fits" the data. The "best fit" model can be assessed as the model, which minimises the deviation of the data from the smoothed model. This "goodness of fit" is measured by taking the span of "Date" in the model, which minimises the

sum of the squares of the deviance residuals. It must be pointed out that apart from minimising the sum of the squares of the deviance residuals, it is important to look at the plot of these residuals to ensure that they have a reasonably uniform distribution over the whole time series, and that there is no evidence of overcorrection.

The initial model used in Splus was as follows;

> output1_gam(formula=allmort~lo(Date, .5).....etc.

output1 is the name of the output file from the model.

gam is the Splus command for a GAM model.

allmort is the total daily deaths in the data set.

lo is the Splus command for a loess smooth (of Date in this case), and .5 is the span of data or window of data used in the smoothing process.

When the model has completed its analysis the command prompt reappears. To view the output of this model it is necessary to type in a command specifying what parameter is required in the model output. Since it is the sum of the partial autocorrelation of the residuals (acf), that is required the specific command is as follows;

> sum(acf(residuals(output1), type ="p")$acf)

The above command basically generates a sum of the autocorrelation function residuals from model output1, and a number is produced on the screen. The process is repeated, changing the values of the span, until a value for the sum of the residuals, which is as close to zero, as possible can be obtained.

Residual sums from smoothing of Date trend

loess span	residual sum
0.5	1.61
0.3	1.60
0.1	1.53
0.05	0.797
0.025	-0.032

Table 8.1

It can be seen that the sum of the residuals has reversed in going from a span of 0.05 to a span of 0.025, this indicates that the span which gives the minimum sum of the residuals must be between 0.025 and 0.05. Other values of span within this region were analysed, and the following values obtained.

Residual sums from smoothing of Date trend

loess span	residual sum
0.04	0.517
0.03	0.179
0.02	-0.29
0.026	0.014
0.0255	-0.0008

Table 8.2

This clearly shows that a span of 0.0255 produces a residual sum,

which is extremely close to zero. It has been decided to use this span of 0.0255 for the initial development of the model. The optimum span for "Date" will be reviewed as other parameters are added to the model.

8.2.2 Day of week effect

Work by Thurston and Kinney [4] has shown that the day of the week can have an effect on morbidity levels. It was decided that some control for a day of the week effect must be incorporated into the model. This was done in SPlus by incorporating the day of the week as a factor in the model. Each day of the week was assigned a number, with 1 for Monday up to 7 for a Sunday. These values were included as a variable in the data set. The model took the following form;

> output_gam(formula=allmort~lo(Date,.0255) + factor(wday).....etc.

Having incorporated week day in the model, the sum of the residuals was again checked to see if the span for "Date" needed to be adjusted.

Optimising Date span

Loess span (for "Date")	residual sum
0.0255	-0.00180
0.026	+0.01364
0.0259	+0.013
0.0257	-0.00166

Table 8.3

It was decided to use a span of 0.0257 for Date in the model for the next stage of the model development.

The model output, which represents the estimated effects on mortality, from the various parameters, is presented in appendix VII. It is clear from the beta and "t" values that there is no pronounced day of the week effect in the data. (An absolute value of "t" > 1.5 is an indication that an observed effect is statistically significant, the bigger the value of "t", the more statistically significant the effect. The bigger the beta value the bigger the estimated effect). It was decided although the effect is very small the control for the day of the week would be maintained within the model.

8.2.3 Temperature

Changes in temperature are well known to be strongly associated with changes in mortality as discussed in chapter 7. It is extremely important that temperature is controlled for in the model. It has already been explained in Chapter 3, that in an Irish context, the weather conditions, which are most favourable to particulate pollution formation, are those associated with a temperature inversion. This is usually a spell of cold weather, so if one wishes to look at the associations between particulate pollution and mortality, and since particulate pollution and cold temperatures appear to be highly correlated, one must effectively eliminate (control) the effects of temperature within the analysis model, in order to view the effects of particulate pollution on mortality. The other aspect of the inclusion of temperature in the model is to consider the lag structure

associated with temperature. The method of assessing the goodness of fit for temperature in the model is to look at the Aikike Information Criteria (AIC) [5] of the model. This determination of the AIC was used to help in the assessment of the goodness of fit of temperature in the model. Minimum temperature was included in the model, with an initial loess span of 0.7 being chosen at random. The model took the following form;

>output2_gam(formula=allmort~lo(Date,.0257)+factor(wday)+
lo(tempmin,.7)...etc.

The temperature term was successively replaced with minimum temperature lag 0 up to lag 6, and the AIC calculated for each model.

Temperature Lag

Min. Temperature	**AIC**
lag 0	6147.846
lag1	6145.299
lag 2	6138.558
lag 3	6120.941
lag 4	6106.964
lag 5	6110.954
lag 6	6115.407

Table 8.4

This shows that temperature out to lag 6 is associated with current day mortality. The actual lag, which gives the minimum AIC, is minimum

temperature with a lag 4. The AIC value starts to rise after lag 4. It does not make sense to assume that current day mortality should only be modelled with minimum temperature from four days previous. In view of the fact that all of the lags of temperature show an association with current day mortality, it was decided to investigate a moving average of minimum temperature, taking a number of different averaging periods.

Various lag structures for temperature

Temperature lags	AIC
lag 0 to lag 1	6151.375
lag 0 to lag 2	6143.843
lag 0 to lag 3	6139.591
lag 0 to lag 4	6136.737
lag 0 to lag 5	6122.821
lag 0 to lag 6	6124.02
lag 2 to lag 3	6128.429
lag 2 to lag 5	6126.045
lag 1 to lag 5	6129.526

Table 8.5

As already pointed out in Chapter 7, the minimum AIC should only be used as a guideline. It was decided that from a medical point of view current day (minimum) temperature should be included in the model, and since there was a strong correlation between temperature and mortality for a number of individual lag values, it was decided to include a moving average

of temperature from lag 0 to lag 5. This can also be justified in that it makes sense that current day mortality due to temperature extremes is more likely following a number of consecutive cold days as opposed to one single cold day. The lags 0 to lag 5 were chosen in that after lag 5 the AIC value started to rise again, this was also the lag structure that produced the minimum AIC value.

Since interest is primarily in the short term or acute effects, it was decided to concentrate on confounders with a time span of the order of one week, having of course included a trend or "Date" term in the model. Having chosen a moving average of temperature of lags 0 to lag 5, the loess span for temperature was analysed, to find the span which produced the minimum AIC value.

Optimisation of temperature component in model

(for temperature lag 0-5)

loess span	AIC
0.8	6121.997
0.7	6122.821
0.9	6120.501
0.95	6122.557
linear	6121.139

Table 8.6

The span, which gives the minimum AIC, is 0.9. Having controlled for temperature in the model, the next meteorological parameter to consider was humidity. The output form the modelling of temperature is presented in appendix VIII.

8.2.4 Relative Humidity

As with temperature it is important to consider the potential confounding that can arise from the relative humidity value, the lag structure of relative humidity also needs to be investigated. This process is the same as that already conducted on the temperature. The model used was of the following form with weekday and temperature also included in the model;

output_gam(formula=allmort~lo(Date,.0257) + factor(wday) +

lo(temp15,.9) +lo (relhum,.7).....etc.

Different lags of relativity humidity were tried in the above model using a loess span of 0.7. Having identified the relative humidity lag that produced the minimum AIC, the span was adjusted to see if the AIC could be further reduced.

Incorporating relative humidity in the model

Relative humidity	AIC
lag 0	6126.472
lag 1	6120.707
lag 2	6135.256
lags 0 to lag 1	6128.893

Table 8.7

It was decided in light of the above figures that although lag 1 produced the minimum AIC value, it is difficult to justify not including current day (lag 0) in the model. The fact that the AIC value rose so dramatically when lag 2 was considered, it was decided not to consider the relative humidity past lag 2. A moving average of lag 0 to lag 1 for relative humidity was chosen for inclusion in the final model. Taking this component for the relative humidity, the value of the span was adjusted to find which span would give the minimum AIC value.

Optimising of relative humidity term in model

Loess span	AIC
0.7	6128.893
0.8	6125.926
0.9	6124.609
linear	6122.885

Table 8.8

The model outputs from the analysis of relative humidity are presented in appendix VII.

8.3 COMPLETION OF THE MODEL

Now that all the available potential confounders have been incorporated into the analysis model, the span for "Date" should be rechecked to ensure that it still corresponds with a minimum sum of residuals.

Recheck of Date optimisation in the model

Loess span	residuals sum
0.0257	-0.0669977
0.027	-0.0178
0.028	+0.0177
0.027	-0.1739
0.0275	+0.00602
0.0274	-.00590

Table 8.9

It was concluded that in the final model a span of 0.0274 would be used for "date". Another measure of the goodness of fit is if the residuals of the overall model show a normal or Gaussian distribution. A histogram of the residuals of the model is shown in graph 8.3, it can be seen that the distribution of the residuals approximates extremely well to a normal distribution. It has been decided that the final version of the model is a

suitable model for the analysis of the data, to look at the correlations between particulate pollution and mortality in Dublin. The final model to be used is as follows, where smoke or the other variables to be analysed will be added to the existing model;

output_gam(formula=allmort~lo(Date,.0274) + factor(wday) +

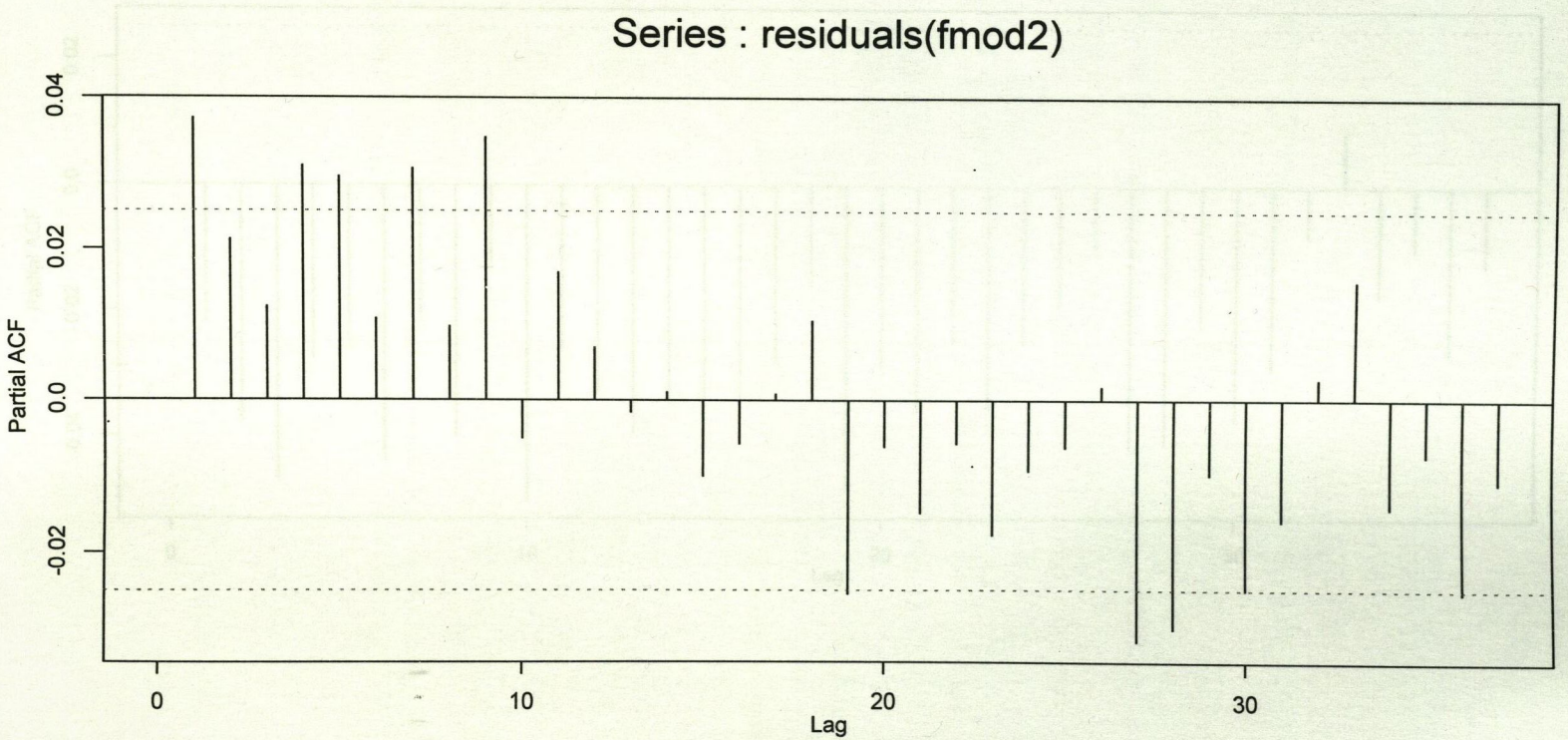
lo(temp05,.9) +

relhum01 + ...etc, data=dataset, family =robust(poisson).

Graph 8.1 shows the distribution of the acf residuals from the final analysis model. Graph 8.2 is presented to show a bad distribution of acf residuals, which would indicate a model, which is unacceptable.

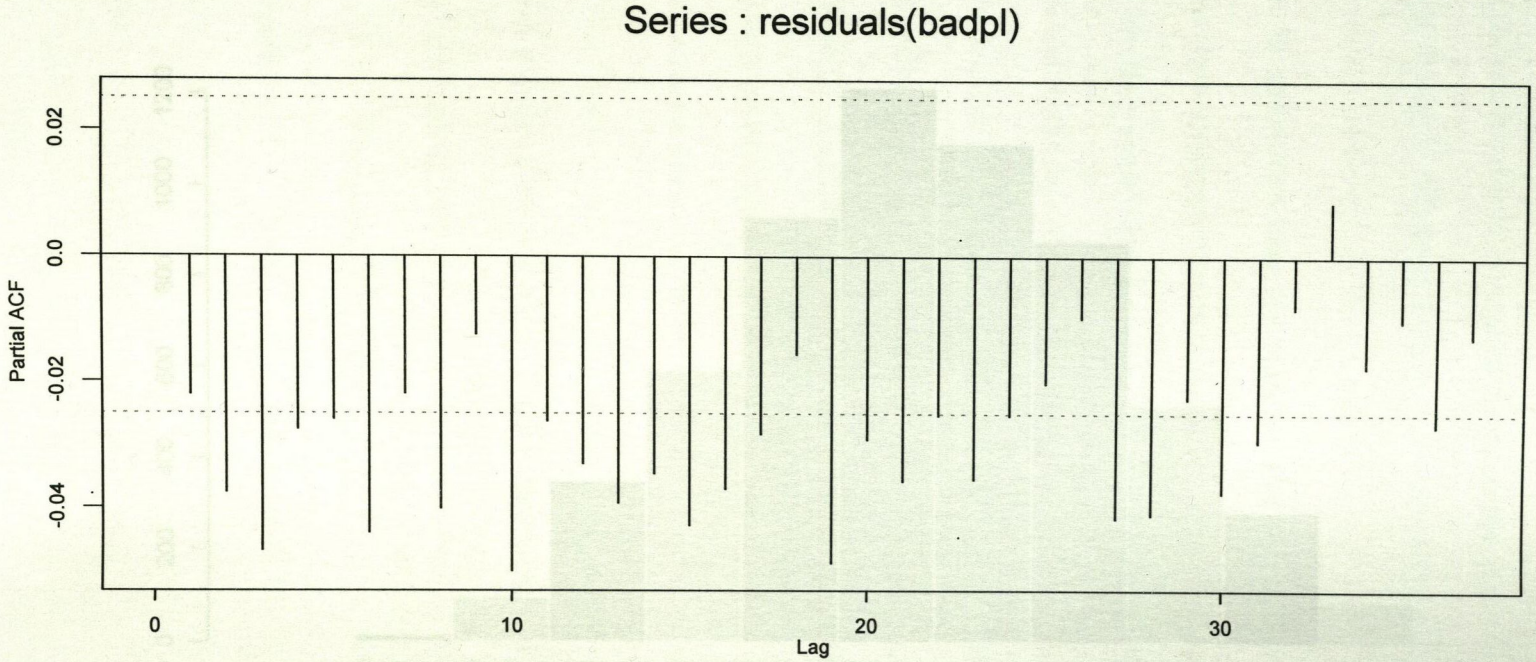
ACF Residuals from final analysis model

Graph 8.1



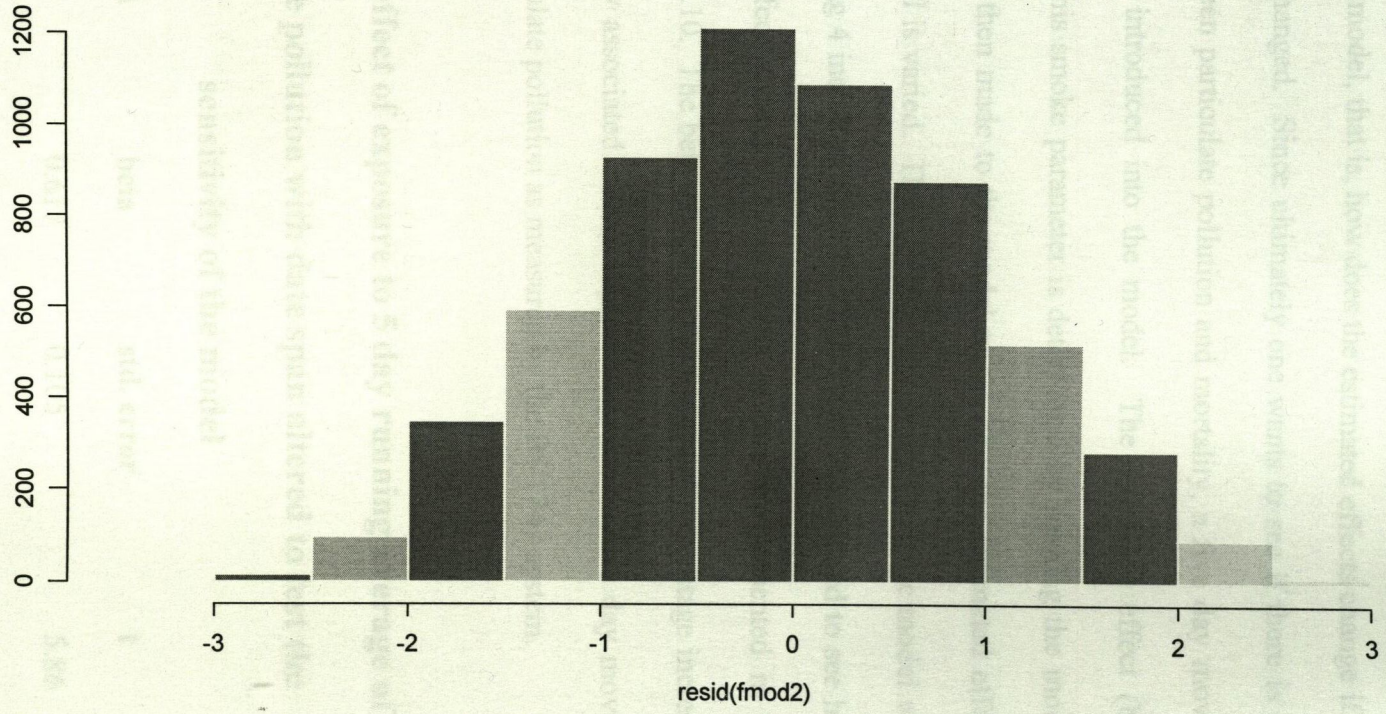
Example of an unsuitable acf residual distribution

Graph 8.2



Histogram of residuals from final analysis model

Graph 8.3



8.4 CHECKING THE SENSITIVITY OF THE MODEL

Having developed an analysis model it is important to check the sensitivity of the model, that is, how does the estimated effects change if the model itself is changed. Since ultimately one wants to see if there is any correlation between particulate pollution and mortality, a five day moving average term is introduced into the model. The estimated effect (beta coefficient) for this smoke parameter is determined by running the model. Adjustments are then made to the model to see how the estimated effects vary as the model is varied. The first step was to run the basic model with smoke lag 0 to lag 4 included, then the "Date" span was altered to see how the estimated effect changed. The results of this are presented in the following table 8.10. The beta values are the estimated percentage increase in daily mortality associated with a $10\mu gm^{-3}$ increase in five day moving average of particulate pollution as measured by the BS 1747 system.

Estimated effect of exposure to 5 day running average of particulate pollution with date span altered to test the sensitivity of the model

Date span	beta	std. error	t
0.0274	0.617	0.105	5.86
0.0137	0.536	0.103	5.2
0.055	0.656	0.106	6.13

Table 8.10

The results in the previous table show that the estimated effects on mortality, as a result of exposure to particulate pollution change as the analysis model is changed. As the span for "Date" is reduced the estimated effect decreases and as the span is increased, the estimated effect increases, this is as expected.

Returning the "Date" span value back to that determined for the model, i.e. 0.0274, the weekday term was removed from the model and the estimated effect obtained. Then the model was run again this time with no temperature term included, and the estimates again obtained, a further run of the model was conducted with no humidity term, and finally the model was run with no weekday term, no temperature term and no humidity term all removed simultaneously from the model. The table of estimated effects for each of these runs of the model is presented in table 8.11.

Estimated effect of exposure to 5 day running average of particulate pollution as various terms are removed from the analysis model

Version of model	beta	std. error	t
complete model	0.617	0.105	5.86
no weekday term	0.611	0.105	5.80
no temperature term	1.02	0.093	11.01
no humidity term	0.652	0.105	6.2
All terms removed	1.03	0.092	11.15

Table 8.11

These results show that the estimated effect changes very little if the weekday term is not included in the model, this is just reaffirming that the day of the week is not a significant factor in relation to this particular population group. The weekday term will be maintained in the model for completeness.

When the temperature term was removed from the model the estimated effect of an increase due to pollution exposure rose dramatically almost doubling, this indicated that temperature is a confounder and must be included in the model, otherwise the estimated effect due to pollution exposure would be over estimated. The fact that this increase in estimated effect was observed when the model was altered also indicates that the model is controlling for temperature.

When the relative humidity term was removed, again there was very little difference to the estimated effect, showing that although humidity can be considered to be a confounder, its effect is quite small.

Finally all of these terms were removed simultaneously from the model, again the estimated effect rises dramatically, but the estimated effect is similar to that when temperature alone was left out of the model. It can be concluded that the temperature term is the largest potential confounder term that is controlled for in the analysis model. The model outputs from the work described in sections 8.3 and 8.4 are presented in appendix VIII.

8.5 SUMMARY

An analysis model was developed for regression analysis of the associations between particulate pollution and mortality in Dublin. This model contained terms for long term trend or "Date", day of the week effect, temperature and humidity. A test on the sensitivity of the model showed that it controlled well for the potential confounders that were included in the model. It should be noted that these were the only potential confounders for which data was available. It would have been of interest to include a variable for influenza episodes, unfortunately no such data is available for Dublin for the period of time under investigation in this study.

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Chapter 9

DATA ANALYSIS

9.1 INTRODUCTION

This chapter presents the analysis of data as conducted in this study. In the initial section, the associations between particulate pollution and mortality were investigated, with particular emphasis on the lag structure between exposure and mortality. A similar investigation was conducted for SO_2 levels, and then both pollutants were investigated simultaneously. The effect of the introduction of the ban on bituminous coal was also studied. Evidence of a medium term exposure effect was also investigated. All of this analysis was conducted using a *Generalised Additive Model* (GAM) [1] in the Splus [2] computer analysis package. The development of the specific model used was outlined in chapter 8.

In this analysis, the results of the output of a particular version of the model are presented in a shortened form. The complete computer output is presented in appendix IX. The estimated effect, called *beta,* the standard error, and the "t" value are all presented. An absolute value of "t" greater than about 1.5 means that there is a significant statistical association between the parameters being investigated. The greater the value of "t", the more statistically important the association. The greater the beta value the greater the estimated effect is, while the error quoted is the estimated error

on the value of beta. It should be noted that to convert the estimated effect, into the percentage rise in mortality associated with a $10\mu gm^{-3}$ increase in pollutant, the beta value as given in the appendicies is multiplied by 1000 to produce the values in the tables presented within this chapter. There are some comments presented on the results within this chapter, but a detailed discussion on all of the results is presented in the following chapter, chapter 10.

9.2 LAG STRUCTURE FOR SMOKE EXPOSURE

In this study, the exposure of the population to particulate pollution is based on the measurements made with the BS1747 [3] system as outlined in chapter 2. This exposure is referred to in this work as "smoke". The lag structure between exposure and current day mortality was investigated; this was done with only one smoke component in the model at a time, univariatly.

Estimated effect at different lags of smoke exposure

Smoke lag	beta	error	t
0	0.252	0.07	3.15
1	0.381	0.079	4.81
2	0.282	0.080	3.51
3	0.206	0.079	2.59
4	0.303	0.078	3.87
5	0.267	0.078	3.42
6	0.333	0.077	4.32

Table 9.1

The values for beta in table 9.1 relate to the increase in total mortality for each $10\mu gm^{-3}$ increase in daily particulate pollution level. It can be seen that there is a positive association right up to lag 6 or one week. The "t" value is significant for all the lag values. Then all of these smoke lags were included in the one model, simultaneously; the output of that is given in table 9.2.

Estimated effect for various lags of smoke exposure estimated simultaneously

Lag	Beta	error	t
0	0.05	0.01	0.48
1	0.3	0.1	2.27
2	0.07	0.1	0.55
3	-0.08	0.1	-0.63
4	0.26	0.1	2.01
5	-0.04	0.1	-0.35
6	0.27	0.1	2.61

Table 9.2

9.3 Choosing the optimum lag structure for smoke exposure

Having studied the univariate and the simultaneously estimated effects for different lags of smoke, it was decided to take lag structures and investigate them more closely. It must be pointed out that in the simultaneously estimated effects there is a potential problem of multicollinearty within the model, this is because there is a strong relationship (correlation) between smoke on the current day and smoke on the previous day. This particular aspect of multicollinearty within a model is discussed by Pope and Schwartz [4]. Taking the univariatly estimated

effects, the beta and "t" values decrease at lag 3, increase again at lag 4 and then decrease again at lag 5. In the simultaneously estimated effects, not withstanding the problems of multicollinearity, the sign of the estimated effects changes at lag 3 and at lag 5. Taking both sets of estimates into consideration, it was decided to use a 3 day (lags 0 to lag2) and a five day (lags 0 to lag 4) moving average of smoke levels. This choice of lag structure is in close agreement with that reported by Anderson, Spix et al.[5] from work in the APHEA project, they reported using a lag structure ranging from 3 to 5 days depending on the particular pollutant in question. From the estimated effects presented here, it can be seen that the beta and "t" values rise again at lag 6, or day 7. It was decided to concentrate the initial part of this study up to lag 4, as the estimated effects began to fall at lag 5, and because the short term or acute effects were those of initial interest in this study.

9.3.1 Comparison of a three and a five day averaged smoke exposures

Comparison of a three and five day averaged smoke exposures

Lag structure	Beta	error	t
lag 0 to lag 2	0.493	0.094	5.24
lag 0 to lag 4	0.629	0.1	5.97

Table 9.3

Both the 3 day and 5 day moving averages of smoke exposure show

a highly significant association with current mortality. These estimated effects are also more than double any of the estimated effects for individual lags. It was decided that smoke exposure on the current day, although not giving the highest estimated effect, it should be included within the model. The fact that, the estimated effects from these 3 and 5 day running averages are significantly higher than those of any individual lag indicates that there is the likelihood of an accumulative exposure effect. This will be investigated in a later section. In view of the fact that the 5 day moving average of smoke exposure shows the strongest association with mortality, it was decided that this 5 day moving average of smoke exposure would be used for the remainder of the acute effect investigations.

9.4 Sulphur Dioxide Exposure

Although not strictly particles, the role of SO_2 in health effects has been the subject of many studies [6,7]. In European air quality guidelines [8], the maximum permissible levels of particulate pollution have been linked to SO_2 concentrations occurring at the same time. In view of the fact that SO_2 data was available for the whole of this study period, it was felt that the associations between SO_2 and mortality must also be investigated. As with the studies on smoke levels, individual lags of SO_2 levels were included in the analysis model and the effects (beta values) estimated.

Sulphur Dioxide lag structure

Lag	beta	error	t
0	0.581	0.22	2.61
1	0.588	0.22	2.63
2	0.61	0.22	2.74
3	0.675	0.22	3.07
4	0.945	0.21	4.32
5	0.71	0.22	3.2
6	0.606	0.22	2.77

Table 9.4

At an initial glance these estimated effects for SO_2 exposure are much higher than those for smoke, (particulate) exposure, it should however be noted that SO_2 levels showed a lot less variation than smoke levels, and hence the "t" values for the SO_2 exposure are lower than the corresponding values for smoke exposure. As with the smoke exposure the estimated effects start to fall off after lag 4, so it was decided to look at the effect of a 5 day moving average of SO_2 from lag 0 to lag 4 inclusive.

Five day moving average of Sulphur Dioxide exposure

lag	beta	error	t
lag0-4	1.2	0.26	4.55

Table 9.5

Again as with the smoke exposure, there appears to be evidence of a cumulative effect of exposure over a number of days. This lag structure is consistent with that chosen for smoke, and with reported studies [5].

9.5 Smoke and Sulphur Dioxide Exposure

Having identified the lag structures for both smoke and Sulphur Dioxide, the next stage of the investigation was to look at the effects of smoke and Sulphur Dioxide when both were included in the model at the same time. Again, the GAM model as developed in chapter 8 was used for the analysis with both smoke lag 0-4 and SO_2 lag 0-4 included simultaneously in the model.

Smoke and SO_2, 5 day moving average of both modelled simultaneously

parameter	beta	Std. error	t
smoke lag 0-4	0.622	0.01	4.7
SO_2 lag 0-4	-0.0137	0.32	-0.041

Table 9.6

This shows that when smoke and SO_2 are both included in the model that all of the effect is attributable to the smoke exposure. The effect attributable to SO_2 actually becomes negative, suggesting that the association of SO_2 with mortality when considered univariatly was attributable to confounding by particulate pollution, while the effect of

particulate pollution was independent and even negatively confounded by SO_2. Based on the above results it was decided to concentrate on the estimated effects of exposure to a five day moving average of particulate pollution alone.

9.6 Estimated effects of smoke exposure to mortality by age group and by cause of deaths.

The data was analysed again using the GAM model using the five day moving average of smoke exposure. The effect was estimated on the total population group, and on all the various subgroups by age and cause of death. These age and cause of death subgroups have been outlined already in chapter 6. Note that the beta values quoted are the estimated effects or increase in mortality associated with a $10\mu gm^{-3}$ increase in five day averaged smoke exposure.

Estimated effect of exposure to a 5 day moving average of particulate pollution

Category	beta	error	t
Total mortality			
Almort	0.616	0.1	5.85
All age0-64	0.22	0.22	0.99
All age65-74	0.594	0.19	3.02
All age 75+	0.934	0.14	6.57
Cardiovascular			
allcardiac/vas	0.57	0.15	3.71
card/vas age0-64	-0.21	0.37	-0.56
card/vas age65-74	0.912	0.28	3.2
card/vas age 75+	0.54	0.21	2.5
Respiratory			
Allresp	1.74	0.23	7.6
resp age 0-64	1.97	0.664	2.97
resp age 65-74	1.06	0.489	2.17
resp age 75+	1.92	0.29	6.55

Table 9.7

Virtually all of these subgroups show a positive association with exposure to particulate pollution, that is mortality in most of these subgroups is seen to rise as particulate pollution levels rise. The smallest, and non significant effect is found in the youngest age group, age 0 to 64, while the most pronounced effects are observed for respiratory deaths, with the biggest effect for respiratory deaths among the elderly, that is the 75 and over age group. There is a small negative association reported for the young age group for cardiovascular deaths, but the effect is not statistically significant with a "t" value less than 1. These results are discussed in more

detail in the next chapter. The dose response curve for the whole population to a 10μgm^{-3} increase in 5 day average particulate pollution is presented in appendix X.

9.7 Robustness of the association with exposure

At the development stages of a model for the analysis of the data a number of very slightly different models were developed. One model, which was similar to the final model chosen, had a temperature component from lag 1 to lag 4. The current day temperature, that is temperature on the day of mortality, was not included. It was found that the min AIC corresponded with the following GAM model;

> output1_gam(formula= allmort~lo(Date,.0274) + factor(wday) +temp14 +lo(relhum, .68).....etc.

The main differences between this model and the final model used in the study is that temperature lag 0 was not included, and neither was a component for relative humidity lag 1. Despite these differences in the two models, the estimated effects were virtually identical; some of the estimated effects from this model are presented for comparison purposes.

Estimated effects using a trial model

Category	Beta	error	t
allcard/vas	0.56	0.15	3.68
allresp	1.7	0.22	7.4
resp age 75+	1.9	0.29	6.54
resp age 0-64	1.8	0.6	2.8

Table 9.8

These estimated effects (for the selection of subgroups shown) are virtually identical to those obtained using the final analysis model, as presented in table 9.7. This shows that the estimated effects are very strong or robust, and that minor variations to the actual model chosen for the analysis, produce no pronounced change in the estimated effects. This fact means that one can have more confidence in the causal association between exposure to particulate pollution and increases in mortality as identified in the analysis of the data.

9.8 EFFECTIVENESS OF THE BAN ON BITUMINOUS COAL

Another major aspect of the analysis in this study was to evaluate the effectiveness or otherwise of the ban on bituminous coal [9]. This ban was not actually on the burning of bituminous coal, but on the marketing sale and distribution of bituminous coal in the greater Dublin area. The ban was extremely effective in reducing particulate pollution levels, as has been discussed in chapter 5, the objective was to see if this reduction in

particulate pollution translated into reduced mortality. The ban came into effect on the 1st September 1990, this gave a series of 3,805 days prior to the introduction of the ban, and 2,314 days after the ban became operative. Again the data was modelled using the GAM model as developed and used for the other analysis. A variable was introduced to represent the ban, having a value 0 up to the 31st. August 1990, and a value of 1 after that date. The beta values quoted in the following table represent the percentage reductions (additions) in mortality in each of the sub groups, and in the population as a whole as a function of the ban.

Estimated effect in each subgroup as a consequence of the introduction of the coal ban.

Category	beta	error	t
total mortality			
allmort	-2.3	1.27	-1.81
all age 0-64	4.01	2.6	1.51
all age 30-64	0.48	2.7	0.17
all age 65-74	0.86	2.43	0.356
all age 75+	-7.0	1.7	-4.15
all age 30+	-3.13	1.2	-2.43
Cardiovascular			
allcard/vas	-3.44	1.88	-1.82
card/vas age 0-64	-3.59	4.4	-0.88
card/vas age 30-64	-4.06	4.4	-0.99
card/vas age 65-74	-1.39	3.6	-0.38
card/vas age 75+	-6.61	2.54	-2.59
card/vas age 30+	-3.5	1.88	-1.89
Respiratory			
allrespir	-17.5	3.0	-5.07
resp age 0-64	-8.67	10.4	-0.828
resp age 30-64	-10.3	10.7	-0.958
resp age 65-74	-12.0	7.0	-1.65
resp age 75+	-21.65	4.4	-4.9
resp age 30+	-17.8	3.47	-5.12

Table 9.9

Overall there is a statistically significant reduction in mortality associated with the introduction of the ban in Dublin. None of the subgroups which show a positive association are statistically significant with "t" values less than 1. As has already been explained in chapter 6, in order to study the effects of the ban, it was important to consider changes in the population in the period before the ban, compared to the period after the ban. It was found that there were significant changes in the overall population, but that if one concentrated in the over 30 age group the population remained virtually static, hence the presentation of results for the over 30 age group. A detailed discussion of these results are presented in Chapter 10.

9.8.1 Sensitivity analysis of the ban effect

It was decided to conduct an investigation into the sensitivity of the analysis with respect to the introduction of the ban. The parameter representing the introduction of the ban was altered to show the effects attributable to a ban being introduced on the 1st September 1987, three years before the actual ban was introduced, and a second for a ban being introduced on the 1st September 1993, three years after the actual introduction of the coal ban. As explained in chapter 6 only the 30+ age group was considered, this was to control for population changes.

Sensitivity of the effective of the coal ban modelling

ban date used	beta	std. error	t
1 Sept. 1987 (pre ban)	+ 3.88	1.3	2.8
1 Sept. 1990 (actual)	-3.13	1.28	-2.44
1 Sept 1993 (post ban)	-1.8	1.2	-1.4

Table 9.10

9.9 Investigation of a medium term exposure effect

When studying the mortality data, there was a very obvious seasonal component observed, with increased mortality in the winter months, and significantly lower mortality during the summer period. Clearly, a lot of the season variation in mortality is explained by temperature variations. The months of December and January show the highest mortality, but mortality levels into March were often higher than one might expect. This hinted at the possibility that there may well be a longer term exposure component in operation. In chapter 3 it was pointed out that Ireland experiences typical winter time pollution episodes, and the variations in pollution levels between winter and summer have been discussed in chapter 5. It was decided to investigate if there was any evidence of an effect due to accumulative exposure to particulate pollution. The results in table 9.1 also showed a positive effect with exposures at all the lag values investigated. There was evidence of an effect at lags greater than those normally used in the study of acute effects. It was decided that both a 14 day and a 30 day running average of smoke exposure would be investigated. The following table presents the results that were obtained when 5 day, 14 day , 30 day, 45 day and 60 day running averages of particulate pollution were included individually in the model.

Estimated effects of accumulative 5 day, 14 day 30 day, 45 day and 60 day particulate pollution exposure (estimated univariatly)

Category	beta	error	t
allmort			
smoke lag 0-4	0.616	0.10	5.85
smoke lag 0-13	1.24	0.12	9.8
smoke lag 0-29	2.21	0.14	15.4
smoke lag 0-44	2.58	0.15	16.72
smoke lag 0-59	2.57	0.16	15.58
allcard/vas			
smoke lag 0-4	0.57	0.15	3.71
smoke lag 0-13	1.24	0.18	6.72
smoke lag 0-29	2.0	0.2	9.5
smoke lag 0-44	2.38	0.26	10.54
smoke lag 0-59	2.4	0.24	9.95
allresp			
smoke lag 0-4	1.74	0.23	7.56
smoke lag 0-13	3.27	0.28	11.36
smoke lag 0-29	6.4	0.38	19.53
smoke lag 0-44	7.9	0.23	22.5
smoke lag 0-59	8.6	0.38	22.21

Table 9.11

The results in table 9.11 show some level of consistency, in that in going from a 5 day moving average to a 14 day moving average, the estimated effects all virtually double in value, and the "t" values almost double as well. Since these estimates reflect the estimated increase in mortality associated with an increase of $10\mu gm^{-3}$ of pollutant averaged over the period of time in question. The estimated effect due to a 30 day accumulative exposure shows an even stronger association with the estimated effects almost doubling compared with those for the 14 days period. The change in estimated effect in progressing from a 30 day moving average of exposure to 45 day or 60 day exposures shows minimal change compared with the 30 days. The respiratory mortality group is the only one which shows a noticeable rise in the estimated effects, but even then the rise is quite small in comparison to the doubling effect observed in going from 14 days to 30 days. It was then decided concentrate the study to look at the 5 day moving average and the 30 day moving average within the same model. The 30 day moving average was chosen in preference to the 14 days moving average as this showed the highest estimated effects and the highest "t" values and since in taking longer exposure periods there was little change in the estimated effects.

Simultaneous estimate of effect due to accumulative particulate pollution exposure over 5 days and 30 days

Category	beta	error	t
allmort			
Smoke lag 0-4	0.0027	0.014	0.19
Smoke lag 0-29	0.218	0.019	11.55
allcard/vas			
Smoke lag 0-4	0.0036	0.020	0.174
Smoke lag 0-29	0.197	0.0277	7.08
Allresp			
Smoke lag 0-4	0.021	0.030	0.69
Smoke lag 0-29	0.625	0.0426	14.64

Table 9.12

These estimates attribute virtually all of the estimated effects to the longer term exposure when it is considered simultaneously with the shorter term. There is of course the problem of multicolinearity, and so taking a 5 day moving average of particulate exposure, and a 30 day moving average of same, it is to be expected that these would be highly correlated, it is important that care is taken in interpreting such results. In view of the highly significant effects attributed to the 30 day accumulative exposure it was decided to look in more detail at some longer exposure intervals.

9.9.1 Investigation of the lag structure of medium term exposure

Following from the results presented in table 9.11 it was decided that a more detailed investigation of the length of this medium term exposure phenomena was required, it was also felt that this investigation should be conducted since the estimated effects appeared to be rising slightly at the lags which had been investigated. The estimated effect of exposure to 5, 14, 25, 30, 35, 40, 45, 50, 55, 60 and 90 day exposures were calculated, for all mortality by each age group, and for all respiratory mortality and respiratory mortality age groups. The results from this analysis is presented in the following tables.

Estimated effect of exposure at various running averages of particulate pollution exposure

All mortality age 0-64

Lag	beta	std.error	t
0-4	0.22	0.22	0.99
0-13	0.36	0.27	1.33
0-24	0.44	0.29	1.48
0-29	0.455	0.30	1.49
0-34	0.513	0.314	1.63
0-40	0.60	0.32	1.88
0-44	0.645	0.325	1.98
0-49	0.67	0.33	2.00
0-54	0.749	0.34	2.19
0-59	0.71	0.34	2.07
0-89	1.29	0.37	3.41

Table 9.13 a

Estimated effect of exposure at various running averages of particulate pollution exposure

All mortality age 65-74

Lag	beta	std.error	t
0-4	0.59	0.19	3.02
0-13	1.58	0.2	6.72
0-24	2.22	0.26	8.43
0-29	2.35	0.27	8.71
0-34	2.45	0.28	8.76
0-39	2.54	0.29	8.9
0-44	2.65	0.29	9.13
0-49	2.55	0.30	8.5
0-54	2.56	0.31	8.32
0-59	2.64	0.31	8.5
0-89	2.89	0.35	8.36

Table 9.13 b

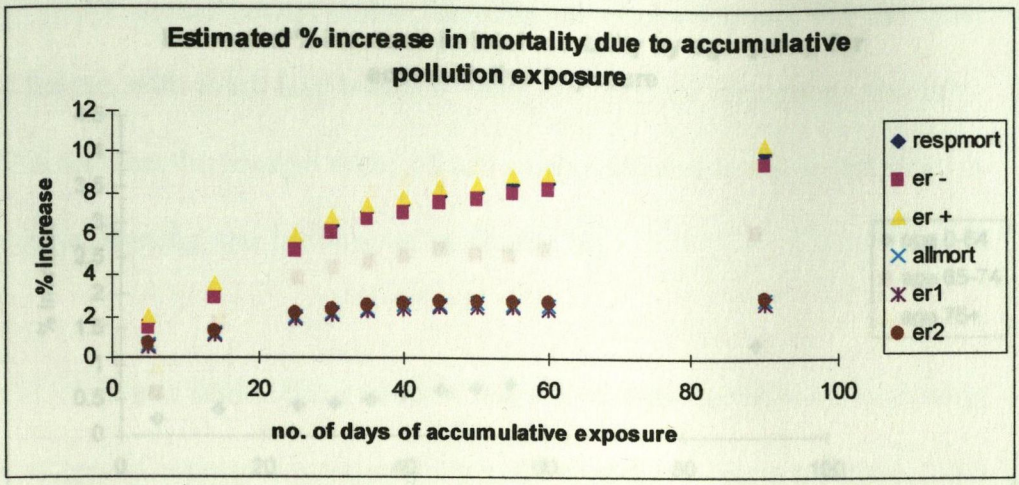
Estimated effect of exposure at various running averages of particulate pollution exposure

All mortality age 75+

Lag	beta	std.error	t
0-4	0.93	0.14	6.57
0-13	1.64	0.17	9.44
0-24	2.84	0.19	14.8
0-29	3.13	0.19	15.94
0-34	3.45	0.20	16.95
0-39	3.62	0.20	17.32
0-44	3.68	0.21	17.35
0-49	3.79	0.22	17.33
0-54	3.75	0.23	16.7
0-59	3.69	0.23	16.15
0-89	3.86	0.26	15.06

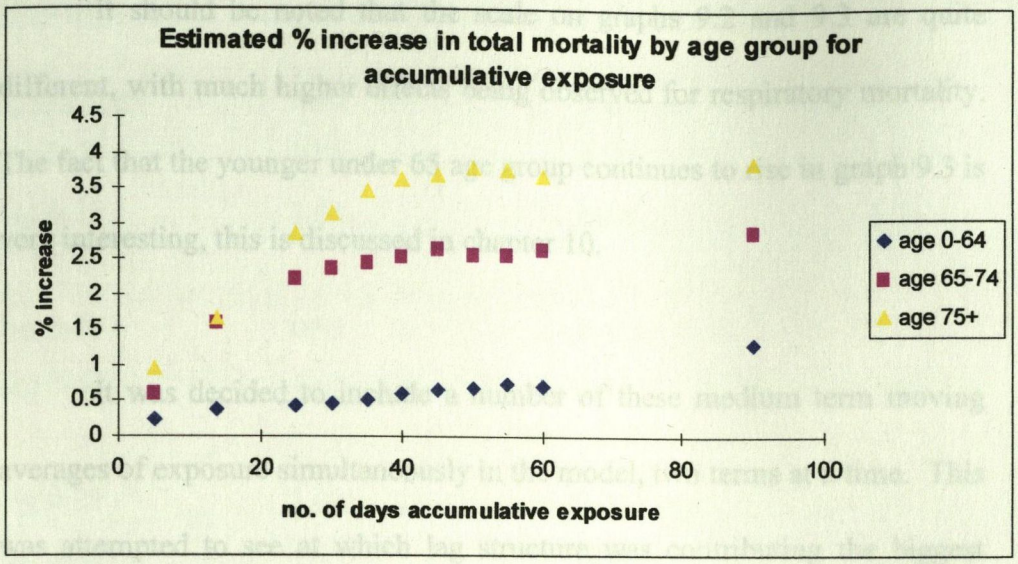
Table 9.13 c

Since all of these results show a certain level of consistency, it was decided to plot these on a graph to aid interpretation of the relationship between exposure and estimated effect. The data for all mortality and for respiratory mortality is presented in graph 9.1.



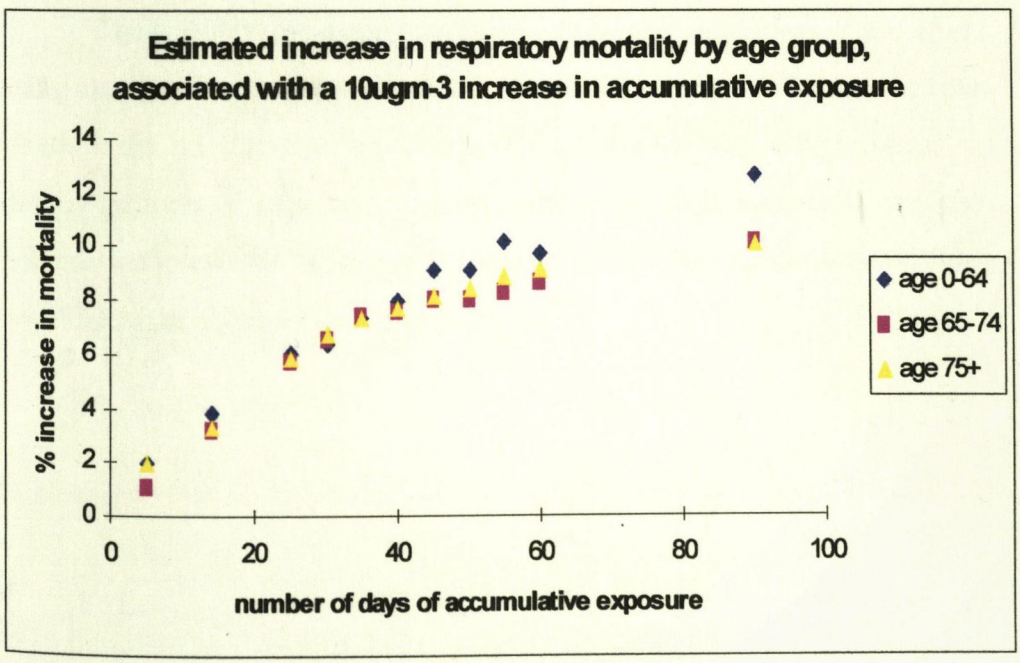
Graph 9.1

The above graph shows the estimated increase in total mortality associated with an increase in particulate pollution of $10\mu gm^{-3}$, for various accumulative periods. The errors on the estimates are also shown on the graph. It was then decided to present the same type of information by age group, for all mortality, in graph 9.2, and for respiratory mortality by age group in graph 9.3 The errors are not shown on graphs 9.2 and 9.3 to avoid clutter on the graphs, but the values have been presented in tables 9.13 a,b,c .for all mortality , and the data for graph 9.3 is contained in appendix XIV.



Graph 9.2

All of these graphs are of a similar shape, showing a sharp rise in estimated effect as accumulative exposure goes up to about 30 days, then the estimated effect starts to level off, reaching a maximum at about 45 days.



Graph 9.3

It should be noted that the scale on graphs 9.2 and 9.3 are quite different, with much higher effects being observed for respiratory mortality. The fact that the younger under 65 age group continues to rise in graph 9.3 is very interesting, this is discussed in chapter 10.

It was decided to include a number of these medium term moving averages of exposure simultaneously in the model, two terms at a time. This was attempted to see at which lag structure was contributing the biggest effect. The problem with this type of analysis is that it is highly prone to multicollinarity within the model and should only be used as an approximate guide.

Simultaneous estimates of medium term exposures

Categories	beta	std.error	t
lag 0-29	1.53	0.29	5.18
lag 0-59	1.08	0.34	3.21
lag 0-29	0.91	0.42	2.14
lag 0-44	1.66	0.45	3.64
lag 0-29	1.61	0.21	7.7
lag 0-89	1.37	0.26	5.13
lag 0-44	2.68	0.55	4.8
lag 0-59	-0.18	0.5	-0.3
lag 0-44	2.05	0.28	7.19
lag0-89	0.78	0.34	2.3

Table 9.14

These results are again remarkably consistent with most of the effect being attributed to the 45 day moving average of exposure. This is the case whether the 45 day moving average is compared with either longer or shorter periods of exposure. These results are also consistent with the information presented in graph 9.1 which shows this accumulative effect levelling off at about 45 days exposure.

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Chapter 10

DISCUSSION

10.1 INTRODUCTION

This chapter contains a detailed discussion on all of the material presented in this work. The most important aspects of the work from each chapter are covered, and an in depth discussion on the results from the study is presented.

10.2 AIR POLLUTION AND HEALTH

In Chapter 1 the association between air pollution and mortality was reviewed, with reference to some of the most infamous episodes of severe particulate pollution and mortality, from London [1](UK) and Donora Pennsylvania [2]. In addition recent research [3,4,5,6] suggests that such extremes of pollution as those observed in London are not necessary for adverse health effects to occur, and that adverse health effects can be observed at much lower particulate pollution levels.

In Chapter 5 it was shown that concern about air pollution and adverse health effects is not new in Dublin, and that in the 17th Century Swift [7] reported that doctors advised their patients to move to the suburbs away from the smoke of the city. In the 1920`s there was renewed interest in air quality measurements in Dublin with studies from Boylan [8], followed by a series of publications by Leonard [9-14] in the 1940`s. Leonard made a

significant number of very worthwhile observations, he linked short term changes in mortality to short term changes in particulate pollution levels, and specifically for changes in respiratory mortality. He attributed the high pollution levels in winter to domestic coal burning, he also observed a reduction in pollution levels which he linked to shortage of coal during the second world war, the extent of this reduction in pollution levels was quite similar to that observed following the introduction of the coal ban in 1990. Leonard also tried to investigate the lag structure between exposure to pollution and excess mortality, but due to lack of suitable computing power at the time; he was unable to come up with a conclusive answer. He was however able to report that the level of respiratory deaths in the Dublin County Borough was significantly higher than for the rural areas of greater Dublin. Leonard observed the lowest number of respiratory deaths within his study for 1941, which was the winter with the lowest particulate pollution levels, indicating a possible causal link between airborne particulate pollution levels and respiratory mortality in Dublin.

In the early 1980`s Kelly and Clancy [15] reported on a severe pollution episode in Dublin which they linked to increased mortality in St James`s Hospital Dublin. Clancy et al [16] have also conducted a retrospective study on this same pollution event but studied data for the whole of Dublin County Borough, and confirmed the earlier findings that the increased mortality was associated with the pollution event, and that there was a huge increase in respiratory mortality. There was widespread concern in Dublin during the 1980s about high pollution levels. The Royal

Dublin Society organised a seminar on air pollution [17], focusing on the possibilities for alleviating the pollution problem in the city. The Irish Government passed legislation to introduce a smoke free zone [18] in the Dublin suburb of Ballyfermot in an attempt to reduce particulate pollution levels in the area. As this was not very successful, the Government then introduced legislation, which banned the marketing, sale and distribution of bituminous coal [19]. This ban proved highly successful at reducing particulate pollution levels. The results presented in Chapter 5 show that the ban on coal sales reduced average pollution levels by 67%. There was also a significant reduction in the maximum daily pollution values. These improvements in air quality have been maintained for the six years since the introduction of the coal ban.

10.3 SOURCES OF PARTICULATE POLLUTION

Chapters 2 and 3 detailed information on the nature; properties and techniques used to measure ambient particulate pollution were presented. The conditions, which favour particulate pollution in an Irish context, were also outlined. The Warren Spring [20] report indicated that domestic coal burning, in open grates, was the main contributor to particulate pollution in Dublin. The large and sustained reduction in particulate pollution levels in Dublin following the coal ban indicates that domestic coal burning was the main contributor to particulate pollution in Dublin. In the period following the introduction of the coal ban in Dublin, when no such ban was in operation elsewhere in Ireland, other major urban [21] centres continued to experience particulate pollution problems. It is also interesting to note that

Leonard [13] observed an improvement in air quality in Dublin when coal was not available for domestic use during the second world war. Nolan and Docherty [22] attributed the higher pollution concentrations that they measured, to the domestic and office heating systems, these would have been primarily solid fuel based at the time of their studies. Winter time pollution levels were significantly higher than those for the remainder of the year, clearly demonstrating that Ireland was prone to the classic winter time type pollution. It is also clear from the work of Bailey [23] that the Government initiative [24] to reduce the national dependence on imported oil actually compounded the problem of particulate pollution, and cost factors [25] also contributed to the high usage of bituminous coal.

It is doubtful if the ban on bituminous coal would have been so successful had it not been for the fact, that natural gas had become widely available at about the same time that the coal ban was introduced. This made it possible for consumers to switch to an alternative fuel.

It must be pointed out however that there are limitations with the Black Smoke [26] method of particulate pollution measurement, as this system is very much dependent on the "blackness" of the particulate matter. Not withstanding this, it is clear that particulate pollution levels fell dramatically in Dublin following the introduction of the coal ban. There may well have been particulate pollution present which was not easily measured using the Black Smoke method, but it can be argued that the concentrations of such particles were likely to be similar in the period before and after the coal ban

came into operation.

10.4 PARTICLE INTERACTIONS

Any health implications from exposure to particulate pollution are only plausible if there is a mechanism of interaction, which can be shown to exist between the particles and the human body, and more specifically the human respiratory system. Chapter 4 shows that there is a body of scientific evidence that airborne particles interact with the human body. Burke and Nolan [27] showed that if a person breathes in particles that the concentration in the exhaled air is lower, implying that particles have been retained by the respiratory system. Bailey et al.[28] showed that particles of a certain size range can have a mean residence time in the body of up to 300 days.

10.5 DATA

The work of this thesis has been to examine the links between particulate air pollution in Dublin and overall mortality. To be able to conduct such a study it is important that one has a comprehensive base of data on all of the following important parameters, such as temperature, humidity, particulate pollution and mortality. It was shown in Chapter 5 that there was extensive data on particulate pollution levels available to this study. The study period is from the 1st April 1980 to the 31st December 1996, this comprises of 16.75 years, or 6119 days. For the whole of the study period there are only 42 days for which no pollution data is available, the estimation of values for those days with missing values was explained in chapter 5.

Meteorological data was available for every day of the study period and complete mortality data was also available for the whole of the study period. This mortality data was sorted by age groups and by cause of death as described by the ICD-9 [29] system of classification. The average daily number of deaths was 13.12, and the total number of deaths used in the study was 80,307. The only information, which was unavailable to the study, was evidence on the occurrence of influenza episodes, as no records existed. The database used for this study was extensive in respect of all the parameters used. The average daily and total numbers of deaths in the study allowed a comprehensive statistical analysis to be conducted on the data.

10.6 STUDY METHODOLOGY

Having such a long time series of daily data available made this database ideal for a time series study. It was decided to conduct a regression analysis of the data using Generalised Additive Models [30] (GAM). The use of such techniques in epidemiological studies has been growing [31], with a significant amount of published work [32,33] using such techniques. This same technique has also been adapted by a European multicentre study [34] on the health effects of air pollutants. The advantage in using the GAM analysis is that the results from this study can be easily compared with the other studies, which have used the same techniques. The methodology of using GAM models has been explained in Chapter 7, the development of an analysis model has been outlined, and the techniques by which confounders can be included into the model has also been discussed. It has been shown that the approach of using a GAM to analyse data similar

to the data available in this study is an acceptable method of analysis, and is currently the most widely used method for this type of study.

In Chapter 8, the development of the analysis model used in this study was outlined. The methods, by which "date", day of the week, temperature and humidity effects, all of which are potential confounders, were controlled for was explained in detail. In relation to "date", it was found that a smoothing term of span 0.0274, or more specifically 167 days, controlled best for long term changes in the data. This 167 day term is very close to a half a year, and can be considered to control for seasonal variations within the data. It was shown in a plot of mortality against time, that there is a strong seasonal component in the data, with significantly higher deaths in winter than in summer. A term for the day of the week was also included in the final model, some studies [35] have shown that morbidity can vary with the day of the week, there was no strong evidence of a day of the week effect in this study, but the term was retained in the model for completeness.

A number of published studies have shown that there is a strong link between mortality and ambient temperature [36,37,38], and in particular with extremes of temperature [39]. The relationship between temperature and mortality for this data set is shown in appendix XIV, where the classic "U" shape is observed, with increasing mortality as the temperature moves to either extreme. It was decided to use minimum temperature in the model, in that in the Irish situation air pollution events are primarily a wintertime

phenomena and are highly correlated with low temperatures, this has been discussed in Chapter 3. The lag structure of temperature was investigated, and it was found that the highest correlation between minimum temperature and mortality corresponded with a lag of 4 days, that is current day mortality was most strongly associated with minimum temperature of four days previously. This result is highly consistent with the published work of Kalkstein and Davis [39], who reported that the lag structures were longer in winter (cold weather) and that mortality occurred up to 3 days after the offending weather. For the purposes of an analysis model it was decided that to exclude current day, and lag 1 to lag 3 minimum temperatures in favour of just including minimum temperature lag 4 in the model is extremely difficult to justify, and so a series of running averages of minimum temperature were investigated. The structure, which gave the best fit, was a running average of minimum temperature lag 0 to lag 5 inclusive. This seems to be plausible, as a number of consecutive cold days would be expected to more detrimental to health as opposed to one single cold day. In the final analysis model, a running average of lag 0 to lag 5 of minimum temperature was utilised. Relative humidity was also included in the model, the lag structure which gave the best fit was a running average of lag 0 and lag 1 of relative humidity, again this is consistent with the findings of Kalkstein and Davis [39].

10.7 ROBUSTNESS OF THE ANALYSIS MODEL

The model, which was used for the analysis of the data, contained controlling terms for "date", day of the week, temperature and relative humidity. When these terms were removed one at a time from the model, the estimated changes in mortality associated with pollution exposure changed, and basically the estimated increase in mortality went up as the potential confounders were removed from the model, this showed that the model was controlling for these terms. The most noticeable effect on mortality was for ambient temperature, when this temperature term was removed from the model, the estimated effect of particulate pollution was almost doubled, (Table 8.11), clearly indicating that temperature is very important and must be included in the model. The estimated effects of all the other potential confounders were significantly lower than temperature. It was shown that the final model controlled well for potential confounders and was a suitable model to use for the analysis of the data. It was also shown in Chapter 9, Table 9.8, that if a different model had been used, the estimated effects were still quite similar to those obtained using the final analysis model. This served to indicate the robustness of the effects.

10.8 REGRESSION ANALYSIS OF THE DATA

The objective of this study has been to examine the links between particulate air pollution and mortality in Dublin. When particulate pollution, in the form of the measurements made with the Black Smoke method were incorporated into the analysis model, a positive correlation between smoke and mortality was observed. That is, as smoke levels rose

so too did mortality. This positive association was seen for all days out to lag 6 (Table 9.1). When these lags of smoke exposure were considered simultaneously, some of the estimated effects became negative. Schwartz and Pope [40] advised that multicollinearity within the data can be a problem, and that it is not uncommon for the sign of the estimated effect to change when a number of terms are considered simultaneously, this is what happened with the data presented in Table 9.2. As with temperature the highest estimated effect for smoke exposure was not with the current day pollution levels, but with lag 1. In view of the fact that at all the lags investigated, lag 0 to lag 6, a positive association was observed, a running average of lags 0 to lag 2 (3 days), and lag 0 to lag 4 (5 days) was investigated. The 5 day moving average of pollution exposure gave the highest estimated effects, and so this was chosen for most of the remainder of the analysis. Wichmann et al [41] also report that if one considers a moving average of particulate pollution, that the association becomes more pronounced after a lag of two days is considered. Dockey et al [42] reported an association between mortality and particulate exposure to a lag of 3 days. Pope et al [43] used a 5 day mean of particulate exposure in their studies. The use of a 5 day running average of particulate pollutant exposure is not inconsistent with a number of other published studies, and it is consistent with this particular data set.

10.9 SULPHUR DIOXIDE EXPOSURE

As the objective of this study was to look at the interrelationships between particulate air pollution and mortality in Dublin and as such the role of Sulphur Dioxide (SO_2) was not being considered, however when it became clear that daily data for SO_2 was available for the whole study period, and for the same monitoring sites as those used for the particulate monitoring, it was felt that this an additional bonus to the study, and that such data should be used. When SO_2 was included in the model, a positive correlation was found between increases in SO_2 levels and increases in mortality, this effect was evident at all lags investigated, Table 9.4. As with smoke a 5 day moving average of SO_2 levels was included in the model, and again a positive association with mortality was observed. However when Smoke and SO_2 were considered simultaneously, Table 9.6, the estimated effect attributable to SO_2 became negative, and all of the estimated effect of increases in mortality was attributed to Smoke or particulate pollution. This would be inclined to suggest that the estimated effect on mortality attributable to SO_2 was confounded by Smoke. This finding is also consistent with the data, in that SO_2 levels were never as high as Smoke levels and also lacked the variability seen in the Smoke. This finding is consistent with a significant number of studies [45-51], which have reported a strong association between particulate pollution, but not with SO_2. Admittedly this is not to say that SO_2 is not important, but that in this study, and in those referenced [44-50] particulate pollution is the predominant pollution element.

10.10 PARTICULATE POLLUTION AND MORTALITY

The analysis of the data for Dublin over the whole time period shows that there is a statistical correlation between increases in particulate air pollution, averaged over 5 days and acute mortality. The data from this analysis is presented in Table 9.7. It shows that total mortality increases by 0.62% for each $10\mu gm^{-3}$ increase in 5 day average pollution level. This estimated increase in total mortality from this study is consistent and similar to the effect reported in other studies [44,51,52] and almost identical to that reported by Pope et al [43].

When age groups for age of death are considered, there is no statistically significant effect observed in the under 65 age group. There is a 0.6% increase in mortality observed for the middle age group, 65 to 74 years, but the most pronounced effect is observable in the oldest age group, 75 years and over, who show a 0.94% increase in mortality for each $10\mu gm^{-3}$ increase in 5 day average of particulate pollution. Similar research into the acute effect of particulate air pollution has found a much higher effect in the older, over 64 age groups [48]. Kelly and Clancy [15] reported that they observed a mean mortality age of 77, during a severe pollution episode in Dublin in 1982. The findings in this study are again consistent with published research that it is mainly the older, 65 years and over, age groups, which are most at risk from increases in air pollution.

When the cause of death is considered, Table 9.7, there is a bigger effect seen for cardiovascular mortality and respiratory mortality compared

with the overall mortality associated with a $10\mu gm^{-3}$ increase in 5 day moving average of particulate pollutant. Yet again the results from this study which show increased cardiovascular and respiratory mortality in comparison to overall increases in mortality is in agreement with the findings from a number of other published studies [44,48,49,51,54,55]. The results from this study clearly show that total mortality increase as particulate pollution levels increase, and that this increase is most marked in the older age groups, 65 years and over, and also for cardiovascular and respiratory mortality. The most marked effects are for respiratory mortality which gives an overall rise of 1.7% for each $10\mu gm^{-3}$ rise in particulate pollution level, with a 1.9% increase observed in the oldest age 75 and over age group. There is no strong association with particulate air pollution and overall mortality in the under 65 age group, there is an observed effect for this age group for cardiovascular and respiratory mortality.

10.11 IS THERE A THRESHOLD LEVEL

An important aspect of this study is to investigate if there is any evidence of a ***threshold level*** for adverse health effects from particulate pollution to manifest itself, and that below that threshold level there is no real health risk. The International guidelines for air quality [56,57,58] all by default assume that there is a safe level of pollution, in that they are recommending a level, which if exceeded that some remedial action should be taken. When the dose response curve, appendix X, is considered, there is no evidence of a threshold, in fact there is a sharp rise in the curve at low pollution levels, and the slope lessens as the pollution levels increase.

When Schwartz and Marcus [47] and Ostro [59] re-evaluated the data for London, neither of their studies found evidence for a threshold. Likewise, the work of Schwartz and co-workers [42,48,60] again showed no evidence of a threshold. Spix et al [61] also report no evidence of a threshold, but what is important is that they report a dose response relationship similar to that obtained here, this is also similar to the relationship identified by other workers [47,59]. In this study there was no evidence of a threshold level, and this is consistent with other published studies, this does not say that there is no threshold, rather that there is no evidence of one from the work of this study.

Another question which arises is how should such a dose response curve be interpreted, this is addressed in the COMEAP [6] report from the UK, the view expressed in that body of work is that the general evidence is that there appears to be no threshold level, and that at the relative risks per unit exposure are higher when the background levels are lower.

10.12 EVALUATION OF THE EFFECTIVENESS OF THE DUBLIN COAL BAN

On the 1st September 1990 following Government legislation a ban came into force [19] which banned the marketing sale and distribution of bituminous coal in the greater Dublin area. The effectiveness of this ban showed that average particulate pollution levels have fallen by about 67%, and that this reduction in pollution levels has been maintained since then. Thus by targeting the supply, rather than the usage of the fuel, more

effective results could be obtained. This is in stark comparison to the situation which developed in Belfast [62] where coal supplies were available but it was unlawful to use the coal in certain areas, and similar to the experiences with the trial smoke free zones introduced in the Ballyfermot area of Dublin [18]. Research shows that increases in mortality have been identified to correlate with increases in particulate pollution levels, similar results were obtained in this study, this poses the question that if particulate pollution levels fall, will there be a fall in mortality, and if the reduction in pollution is maintained will the fall in mortality be maintained. The introduction of the coal ban in Dublin gave a unique opportunity to study this aspect.

In order to study the periods pre and post the introduction of the coal ban, it was necessary to consider how the population changed over the period of the introduction of the ban. It was shown in Chapter 6 that there were large changes in the younger sections of the population. Therefore in order to evaluate the effect of the coal ban, it was decided to concentrated the analysis in this study, on the population group from age 30 upwards, as this age group showed little change over the whole period of the study, Table 6.2.

Mortality was seen to fall by 3.1%, (for all of the population aged 30 and upwards, Table 9.9) as a consequence of the introduction of the coal ban. This is in agreement with the work of Pope [43] who showed a fall of 3% in Utah when the local steel mill was closed for a period of time due to

industrial action. Increases in particulate pollution level have been seen to have a more pronounced effect on mortality in the elderly population and especially for cardiovascular and respiratory mortality. It is the same groups, which are seen to benefit most from the reduction in pollution levels due to the coal ban. Overall there was no statistically significant reduction in mortality for the 30-64 age group, or for the 65-74 age group, with most of the reduction in mortality confined to the 75 years and over age group. When the cause of death is considered a statistically significant effect is only observed for cardiovascular deaths in the oldest age group, 75 years and over, however for respiratory deaths, there is no statistically significant effect for the 30-64 age group, but there is a 12% reduction for the 65-74 age group, and a massive 21.6% reduction for the 75 and over age group.

"Harvesting"

The suggestion that what is being observed in most of these studies on the acute effects of air pollution is the bringing forward of the day of death, to coincide with the pollution event, and that these people would have died within a few days. The suggestion is that the pollution event has only shortened life by a few days within a highly susceptible population group. The term, which has been applied to this, is "harvesting" [63], where the deaths of the most susceptible are harvested by the pollution event. Schwartz [55] has proposed alternative mechanisms, and the matter is also addressed by the COMEAP group [6], where they say that it is unlikely that the harvesting phenomena fully explains what is occurring.

It is believed that the results from this work, and in particular the effect of the coal ban, show that harvesting does not fully explain what happens to the population during a pollution event. This work indicates that it is not harvesting which is taking place, rather that the pollution event is hastening the death of susceptible individuals, but had they survived the pollution event, they could have lived for a significant period, as opposed to dying within a few days as proposed in the harvesting theory. The sustained reduction in mortality, and the huge decrease in respiratory mortality show, that in the absence of pollution, the susceptible members of the population can actually live for a substantial period of time. It is believed that this work has shown that particulate pollution events can significantly shorten the life expectancy of susceptible members of the community, and not just shortening life by the order of a few days, but possibly of the order of months to years in some cases.

Causality

The COMEAP group [6] in reviewing the evidence of the recent research into particulate pollution and health, comment in their executive summary that "there is clear evidence of associations between concentrations of particles and mortality". They believe that this is a "real relationship and not some artefact of the technique" and that the major difficulty is "the lack of any established mechanism of action". Concluding that "in terms of protecting public health it would be imprudent not to regard the demonstrated associations between daily concentrations of particles and acute effects on health as causal." It is believed that the

associations found between particulate pollution levels and mortality in this study also show the relationship to be causal. The fact that respiratory mortality shows the highest effect as pollution levels rise certainly points to evidence for a causal relationship, and again the effect of the coal ban has demonstrated a major reduction in respiratory mortality, which also lends credence to the causal nature of the relationship between particulate pollution levels and mortality. This study set out to investigate if there was an association between particulate pollution levels and mortality in Dublin; it is believed that it has succeeded in this regard. It was not the intention of this study to identify the mechanisms of interaction, and so this aspect has not been addressed in this work.

10.13 MEDIUM TERM EXPOSURE

This work has shown that there is clear evidence for the existence of a medium term exposure component, which is associated with increased mortality, and more specifically with respiratory mortality. In this work, it was found that there was an exposure term of up to 45 days, which showed a significant association with increases in mortality. It suggests that there is strong evidence for an accumulative effect of particulate air pollution, and that if mean pollution levels rise by a small amount, but that this rise is sustained for a period of time, of the order of 30 to 45 days then this is highly correlated to mortality. Such a finding is consistent with the winter time type of air pollution experienced in Dublin. This finding also helps to explain the success of the coal ban at reducing mortality. It was seen that the coal ban reduced winter time pollution levels by 70%, therefore this

medium term 30 to 45 day exposure had effectively been removed, and therefore any mortality associated with an accumulative winter time exposure must also be significantly reduced.

In attempting to analyse the data to look at an accumulative effect of the order of 30 to 45 days duration, there is always the concern of potential confounding by seasonal or temperature effects. It is felt that the results obtained have controlled well for temperature, the duration of the effect is much shorter than a seasonal effect, and it is the belief that these results clearly show that there is evidence for a medium term accumulative exposure effect to particulate pollution. If the effect was purely due to temperature or seasonal aspects it is highly unlikely that such a strong association would have been observed for respiratory mortality, but rather would have been distributed more uniformly among the various cause of death groups.

There is little evidence in the literature of this medium term aspect being investigated; the APHEA group [34] have concentrated on short term acute effects with lags of between 3 to 5 days. It has been discussed earlier that most studies have not looked at lag structures greater than 5 days, this is possibly due to the London smogs [1] where the analysis was effectively kept to short term or acute effects, and most subsequent studies have followed suit. Pope [64] does investigate medium term accumulative exposure but concentrates more on morbidity than mortality, he does report that during the closure of the steel mill that results suggest "that prematurely of deaths

generally was more than just a few days or weeks and may have been as much as a year or more", this is consistent with the findings on the coal ban reported here. It is interesting to note that Leonard et al [11] looked at the lag structure between exposure to particulate pollution and respiratory mortality for winter time pollution in Dublin, during the years 1939, 1940 and 1941. They reported a lag of 3 weeks for 1939, 4 weeks for 1940 and 8 weeks for 1941. They concluded that it was "not feasible to decide on a definite lag from the data so far available". If one takes an average of these lag values, a lag of 5 weeks or 35 days is obtained; this is within the 30 to 45 day term reported in this work. It appears that Leonard did not attempt to look at short term effects, but based his work on weekly averages of pollution exposure and respiratory mortality figures.

There are a number of other studies which have attempted to look at longer term chronic effects of pollution exposure, Daly [65] and Gardner et al. [66] both showed a relationship between death rates and an air pollution index which was based on coal consumption, Leonard also observed increased respiratory mortality in Dublin in the more polluted winters. These studies did not look at lag structures, but rather identified years in which pollution was high, and so in addition, was mortality. It is highly likely that since these studies linked coal burning to pollution, and since most coal burning would have been seasonal, that is, in winter time, it is therefore possible to explain the observed increases in mortality within those studies in terms of this medium term accumulative exposure.

Most of the recent studies on the long term effects of particulate pollution have concentrated on cohort studies of large population groups [67-70], the first three of these studies have shown positive associations between long term concentrations of ambient particles and increased risks of mortality. Others have shown an association of particulate pollution to increased respiratory symptoms in population groups when comparing locations with differing pollution levels [71-74], in which the pollution levels were different between the locations for a period of time. It is possible that there is an effect hidden within all of these studies, which relates to a medium term accumulative exposure component, but that this term has been lost by annual averaging of pollution levels. There may well be chronic air pollution effects which are strongly related to long term exposure, this study was not really concerned with this aspect, but this work has provided evidence for a medium term exposure component. Such a component may be significant where there are seasonal type air pollution episodes, such as the winter type pollution in Dublin. It is believed that this is an aspect of exposure, which should be investigated in other studies.

The data presented in graphs 9.1 to 9.3 show quite clearly the same shape of response, with a sharp rise in mortality and then levelling off. What is of particular note is that for respiratory mortality, the younger age group, age 0 to 64, shows the highest effect. This is attributed to the fact that there are only a small number of deaths in this group, so any additional deaths would constitute a large percentage increase. The fact that the curve is smooth would indicate that this is a potentially real effect which is being

observed in this group. It is postulated that these deaths are from already susceptible individuals. It is proposed to attempt to verify this hypothesis in future studies.

10.14 GENERAL DISCUSSION

This work has shown that there is evidence of an acute relationship between particulate air pollution and mortality in Dublin, and that this link is most marked with a five day running average of pollution. The strongest effect was observed among the elderly, and for respiratory deaths. It was also observed that there was strong evidence of a medium term exposure effect of the order of 45 days, this also showed the greatest effect in the elderly and for respiratory deaths. This medium term effect also helps to explain some of the aspects of seasonal pollution. This work has also shown that the ban on the marketing, sale and distribution of coal in Dublin has reduced particulate and SO_2 pollution levels. This work has found that the coal ban has been associated with a reduction in mortality levels, both overall, and in certain subgroups, most marked in the elderly, 75 and over age group, and with respiratory mortality. No effort has been made to explain the mechanisms by which mortality occurs due to particulate pollution, nor as to which particles cause these effects, the following observations are made in relation to these items.

It is curious to note that in the few studies which have made direct reference to coal usage, that when the coal usage ceases or is reduced that mortality levels also fall or that respiratory symptoms are reduced

[10,11,14,61,65,66,71,72,75]. Dockery and Pope [76] also report that fine particles tend to be darker in colour, and thus they conclude that the BS method [26] is a good measure of fine particulate mass. It is postulated that coal burning may actually hold the key to future work in trying to identify either the mechanisms, or the particle sizes, which are most highly correlated to adverse health effects. Combustion particles are generally small, and are usually a result of incomplete combustion; this would tend to indicate that it is the smaller or ultrafine particles, which are of most biological consequence. It is suggested that since the smaller particles, less than 2.5μm, $PM_{2.5}$ are now gaining a lot of interest among researchers [69,76,77], perhaps it is worth considering particle concentrations, because at small sizes particle mass is extremely small and particle concentrations become more important. Schwartz et al. [78], Peters et al [79] and Seaton et al. [80] all implicate *ultrafine* particles as having the most pronounced adverse health effects, it was seen in Chapter 5 that condensation Nuclei could be extremely useful in measuring particulate pollution levels [81], it is suggested that it might be worth measuring particle concentrations as well as mass in future particulate pollution studies.

In this study the contribution of motor vehicles to particulate pollution has not been considered, it was not possible to separate out the different sources contributing to the particulate pollution levels in Dublin. The fact that particle levels have fallen so significantly with the introduction of the coal ban indicates that domestic coal burning was the most significant contributor to particulate pollution in Dublin. The fact also that mortality is

seen to decrease with the introduction of the coal ban strengthens the argument that coal was the dominant source of particulate pollution. In relation to motor vehicles the numbers on the roads have risen steadily over the whole period of the study, if motor vehicles were emitting particles which were a significant health hazard, then some evidence should have manifested itself in this study, none was found.

This study has shown the relationship between particulate pollution and mortality in Dublin; the results have all been based on a statistical analysis of prospective data gathered over a 17 year period from 1980 to 1996.

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Chapter 11

CONCLUSIONS

11.1 CONCLUSIONS

Data for Dublin has been analysed for a 17 year period from the 1st April 1980 to the 31st. December 1996. Daily data for particulate air pollution, Sulphur dioxide, temperature, humidity and non-accidental deaths were analysed using Poisson regression methods. The analysis model is consistent with those used in recent studies of a similar nature.

This work has shown that it is highly likely, there is a causal relationship between particulate pollution levels in Dublin and acute mortality. This relationship is most marked for a five day running average of particulate pollution levels. The population groups most effected by increases in particulate pollution are the elderly, over 74 age group, and those dying from respiratory conditions. No evidence was found for the existence of a threshold level. When Sulphur dioxide was considered in association with particulates, virtually all of the effect was attributed to particulate pollution, with Sulphur dioxide having no pronounced effect.

This work also found evidence for the existence of a medium term exposure effect, which is of the order of 45 days. This effect suggests that there is an accumulative aspect to particulate air pollution, and which may be significant where strong seasonal variations exist in particulate air

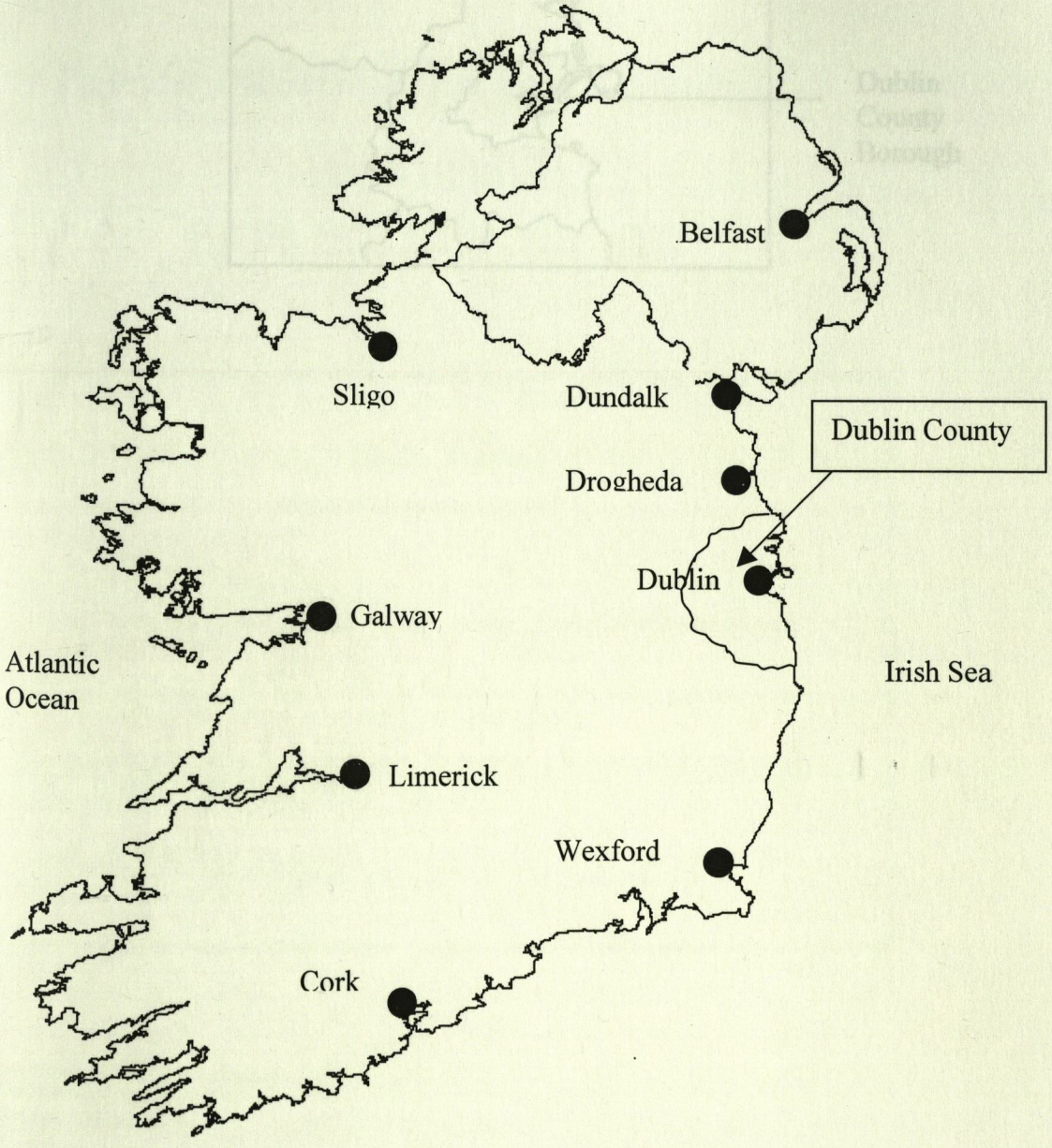
pollution episodes.

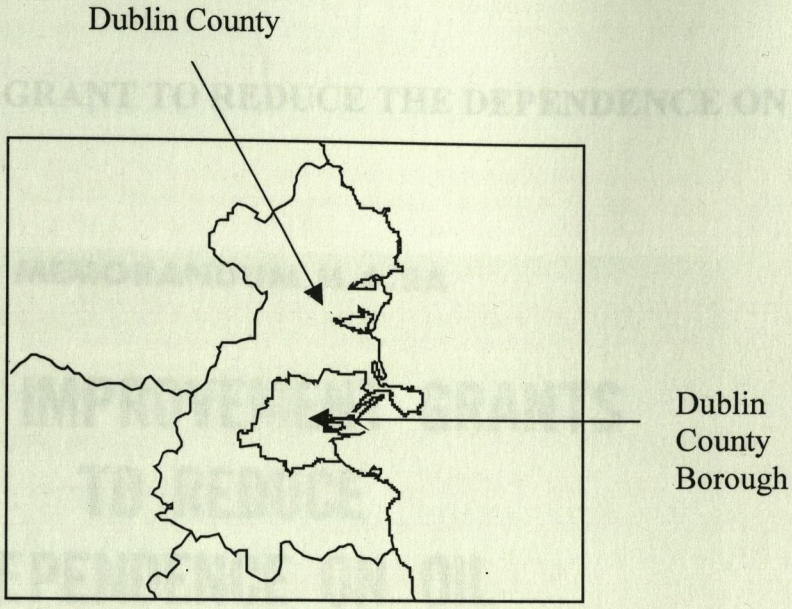
This work also showed that particulate pollution levels fell by about 67% as a consequence of the introduction of the coal ban and that overall mortality in Dublin was reduced by 3% after the introduction of the ban. There was an even more pronounced effect with respiratory mortality, which was seen to fall by 17%. There was a 7% reduction of mortality in the oldest age group as a consequence of the coal ban, the reductions in the younger age groups were not as pronounced. The biggest effect was observed for respiratory mortality in the oldest age group, which showed a reduction of 21.6%.

In summary, this work has shown that air pollution and acute mortality in Dublin are linked. It has shown that the elderly and those with respiratory problems are most at risk from rises in particulate pollution. The work has shown evidence for the existence of a medium term accumulative exposure of the order of 45 days. It has shown that if pollution levels can be reduced, that overall mortality is reduced, and in particular respiratory mortality is reduced significantly.

Appendix I

MAP OF IRELAND SHOWING THE MAIN POPULATION CENTRES




Dublin County
Dublin
County
Borough

Appendix II

GOVERNMENT GRANT TO REDUCE THE DEPENDENCE ON IMPORTED OIL.

MEMORANDUM H.A.2A

HOUSE IMPROVEMENT GRANTS TO REDUCE DEPENDENCE ON OIL

ATTENTION
SPECIAL GRANTS
TO
REDUCE DEPENDENCE ON OIL

KINDLY NOTE:-

1. APPLICATION FORMS AND FULL DOCUMENTATION ARE ATTACHED.
2. TECHNICAL ADVICE ON INDIVIDUAL PROPOSALS SHOULD BE OBTAINED FROM A COMPETENT INSTALLER.
3. PLEASE BE GOOD ENOUGH TO STUDY THE DOCUMENTATION, AND FORWARD THE APPLICATION FORM WITH SUPPORTING DOCUMENTS.
4. A DECISION ON YOUR ELIGIBILITY FOR A GRANT CAN ONLY BE MADE WHEN YOUR APPLICATION HAS BEEN RECEIVED.

Department of the Environment
Housing Grants Section,
O'Connell Bridge House,
Dublin 2.
Phone (01) 713377

August, 1979.

House Improvement Grants to reduce dependence on oil

You can get a special house improvement grant of £600 or two-thirds of the approved cost, which ever is the less, towards the cost of the following works commenced on or after 1st June, 1979:

If you have oil/electric/gas central heating but no fireplace, back-boiler or solid fuel burning appliance.

- the installation of a solid fuel central heating burner, or
- the installation of one fireplace, including a back-boiler, or
- the installation of one solid fuel burning appliance such as a stove or cooker (which will provide a domestic hot water supply).

If you have oil/electric/gas central heating and at least one fireplace but no back-boiler or other solid fuel burning appliance

- the installation of a solid fuel central heating burner, or
- the installation of a back-boiler, or
- the installation of a solid fuel burning appliance such as a stove or cooker (which will provide a domestic hot water supply).

If you have no central heating or back-boiler, but a fireplace

- the installation of a back-boiler, or
- the installation of a solid fuel burning appliance such as a stove or cooker (which will provide a domestic hot water supply).

The cost of necessary plumbing connection i.e. flow and return piping, special tanks and the cost of repairing damage necessarily caused to the fireplace in the course of installation, are reckonable for grant.

You **cannot get** a special house improvement grant towards the cost of:

- the installation of an oil fired central heating burner,
- the installation of a solid fuel central heating burner, where there is no existing central heating system in the house,
- the installation of a copper cylinder,

- the installation of central heating radiators,

- the installation of an additional fireplace, back-boiler or solid fuel burning appliance,

- the connections from a back-boiler or a solid fuel burning appliance to radiators,

- work relating to housing of equipment and storage of fuel,

- work eligible for special grant as specified in this memorandum carried out in a new house or in a house completed within 12 months prior to commencement of the specified works,

- work costing less than £100,

- work carried out in a house not used as a place of normal residence e.g. a holiday house.

- the replacement of an existing fireplace, back-boiler, or solid fuel burning appliance.

Applications for the special grant:

You should apply for the grant on the special application form (coloured blue). You may proceed with the work without awaiting an inspection. When the work is completed you should submit a certificate from the Contractor or Installer setting out details and cost of the grant-aided work and stating that it has been carried out in a satisfactory manner (See green form S.L. 03 attached). If you have doubts about your eligibility for a grant, you may contact the Department. A decision on eligibility for a grant will be made on the basis of the completed application and an inspectors report: payment will be made as soon as possible. The Department, however, reserves the right to seek additional information or require additional work if it is considered appropriate.

The making of a special grant implies no warranty on the part of the Minister in regard to the proper installation of a system or to any damage to the house that may arise from the installation and subsequent functioning of the system.

Other aspects of the grant scheme:

(1) A special grant means that payment of a grant at any time in the past does not debar you from getting a special grant now (except in the case of a new house which was completed within the 12 months prior to commencement of work specified in this memorandum) and that payment of a special grant now does not debar you from getting a further grant (other than a special grant for the types of work specified in this memorandum) at any time in the future.

(2) The seven points standard applying to certain other forms of house improvement grant-aided work does not apply to this special grant.

(3) If a tenant of a private or local authority house wishes to obtain the special grant, he should get the consent of the owner or local authority and meet the net cost (i.e.the total cost less the grant).

(4) A tenant purchaser of a local authority house does not require the consent of the local authority in order to qualify for the grant.

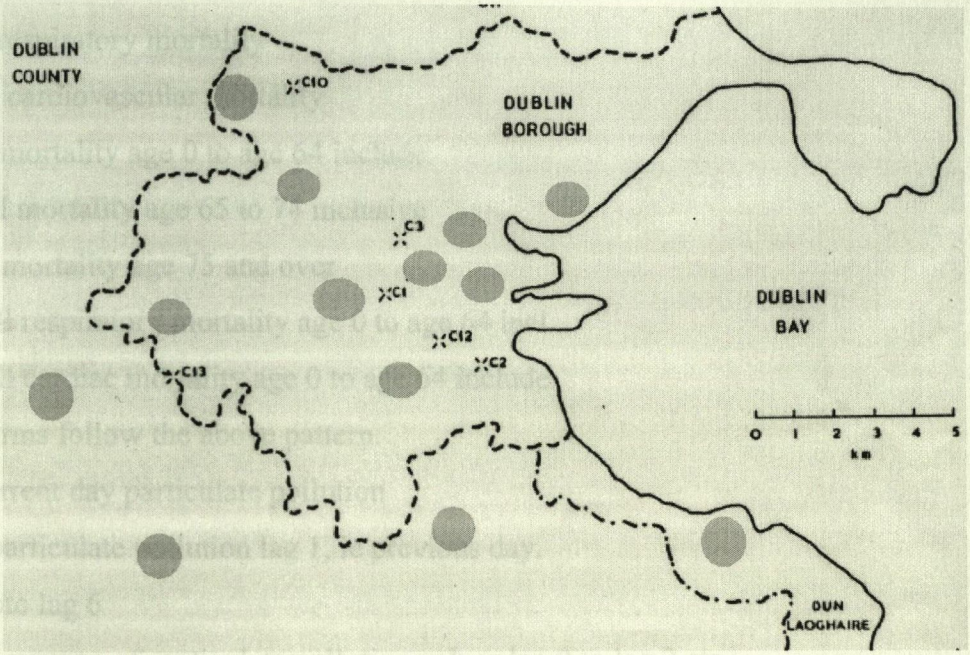
(5) Expenditure under this scheme is allowable for income tax relief under the scheme of residence-related employment operated by the Revenue Commissioners.

IMPORTANT

In order to ensure that an efficient system is installed and that possible hazards such as fire, explosion or otherwise that incorrect installation might cause are eliminated, the Department strongly advises householders to make sure that installation work in their houses is carried out by competent contractors. It is particularly important that the system should be suitably vented and also fitted with a properly located safety release valve, where required. You are, therefore, advised to ensure that the works carried out are in accordance with the relevant standards and codes of practice. In local authority areas where building bye-laws are in operation, the bye-laws must be observed.

Appendix III

MAP OF DUBLIN COUNTY BOROUGH
AND
LOCATION OF POLLUTION MONITORING STATIONS



Monitoring stations

C2 = RDS

C3 = Mountjoy Sq

C8 =. Clontarf

C10 =. Finglas

C12 = Herbert St

C13 = Bluebell

note: Earlsford terrace and Kevin St sites are within 800m of location C1

● Symbol of location of other monitoring stations not used in this study

APPENDIX IV

ABBREVIATIONS USED FOR DATA

The following abbreviations have been used in this work to represent the data in the modelling process:

allmort = all mortality (ICD-9 < 800)

allresp = al respiratory mortality

allcard = all cardiovascular mortality

all064 = all mortality age 0 to age 64 include.

all6574 = all mortality age 65 to 74 inclusive

all75+ = all mortality age 75 and over

resp064 = all respiratory mortality age 0 to age 64 incl.

card064 = all cardiac mortality age 0 to age 64 include.

The other terms follow the above pattern.

Smoke = current day particulate pollution

smklag1 = particulate pollution lag 1, ie previous day.

Similarly upto lag 6

smklag02 = average of particulate pollution values lag 0 to lag 2 etc.

smk030 = average of smoke lag 0 to lag 29, the 30 was used just to indicate that it was a 30 day moving average which was being used, similarly for smk045 etc.

relhum = relative humidity

relhum01 = average of relative humidity lag 0 and lag 1.

wday = weekday term

temp05= average of temperature lag 0 to lag 5.

Appendix V

SAS PROGRAM

This is one of the programs used to extract the raw data from the CSO files, and to summarise the data, into the categories which were required for the analysis.

```
options ls=232 nocentre;
data years;
infile 'c:\R&D\rawdata\deaths\death1.dat';

input @1   stamp    $4.
   @1   dubstmp  $2.
   @1   corkstmp $2.
   @8   death_dd $2.
   @10  death_mm $2.
   @12  death_yy $2.
   @08  died     ddmmyy6.
   @14  institut $1.
   @15  addr     $4.
   @15  address  $3.
   @19  sex      $1.
   @20  marital  $1.
   @21  centen   $1.
   @21  age      $3.
   @27  occup    $1.
   @29  cause    $3.;

   if death_yy = '90';
   if cause < '800';

   if (address in ('000'))
```

```
    then loc = 'Dublin';
 if loc in ('Dublin');

  card064 = 0;
  card6574 = 0;
  card75   = 0;
  resp064 = 0;
  resp6574 = 0;
  resp75   = 0;
  othr064 = 0;
  othr6574 = 0;
  othr75   = 0;
if cause >= '460' and cause <= '519' then do;
  reason = 'respir';
  end;
else
  if cause >= '390' and cause <= '459' then do;
    reason = 'cardio';
  end;
else
  reason = 'other';
 age = int(age);
 if reason = 'cardio' then do;

   if age >= 0 and age <= 64 then card064 = 1;
   if age >= 65 and age <= 74 then card6574 = 1;
   if age >= 75            then card75   = 1;
 end;

 if reason = 'respir' then do;
```

```
  if age >= 0 and age <= 64 then resp064 = 1;
  if age >= 65 and age <= 74 then resp6574 = 1;
  if age >= 75              then resp75   = 1;
end;
if reason = 'other' then do;

  if age >= 0 and age <= 64 then othr064 = 1;
  if age >= 65 and age <= 74 then othr6574 = 1;
  if age >= 75              then othr75   = 1;
end;

 proc sort nodup data=years out=yearsb;
  by  death_yy
     loc
     died
     stamp
     death_dd
     death_mm
     institut
     addr
     sex
     marital
     centen
     age
     occup
     cause
        ;
 proc summary nway data=yearsb;
    class death_yy loc died ;
  var
```

```
  othr064
  othr6574
  othr75
  resp064
  resp6574
  resp75
  card064
  card6574
  card75;

output
out=newsum
sum=;

data newsum;
set newsum;

total = _freq_;
proc sort; by death_yy loc died;
PRoc print label uniform data = newsum split = '/';
by death_yy loc;
title1 '            Death analysis  - all  causes ';
label  total   = 'Total Deaths'
       died    = 'date of death'
       resp064 = 'Respiratory/Age 0-64'
       resp6574 = 'Respiratory/Age 65-74'
       resp75  = 'Respiratory/Age 75 + '

       card064 = 'Cardiovascular/Age 0-64'
       card6574 = 'Cardiovascular/Age 65-74'
```

```
    card75   = 'Cardiovascular/Age 75 + '

    othr064 = 'Other Cause/Age0-64'
    othr6574 = 'Other Cause/Age 65-74'
    othr75   = 'Other Cause/Age 75 + ';

var died

  othr064
  othr6574
  othr75

  resp064
  resp6574
  resp75

  card064
  card6574
  card75
  total;

  sum

  othr064
  othr6574
  othr75

  resp064
  resp6574
  resp75
```

```
card064
card6574
card75
total;

format died ddmmyy8.;
data _null_;
set newsum;
if loc ='Dublin';
file 'c:\R&D\thesis\all90.txt';
Put @1 died ddmmyy6.
   @7 ','
   @13 ','
   @14 othr064 5.
   @19 ','
   @20 othr6574 5.
   @25 ','
   @26 othr75 5.
   @31 ','
   @37 ','
   @38 resp064 5.
   @43 ','
   @44 resp6574 5.
   @49 ','
   @50 resp75 5.
   @55 ','
   @61 ','
   @62 card064 5.
   @67 ','
   @68 card6574 5.
   @73 ','
```

```
    @74 card75 5.
    @79 ','
    @80 total 5.;
run;
```

Appendix VI

SUMMARY OF SOME SPLUS COMMANDS

SPlus is the software package which was used for the final data analysis, the particular version used was worked through the command window. This required a line of command to be typed in, and SPlus then performed the command.
The command line starts with the " > " prompt.

A typical command sequence used in the analysis was of the following form;

> test2_gam(formula = resp75+~ lo(Date,.0274) + factor(wday) + lo(temp05,.9) + relhum01 + smk060, data=dubthesis, family=robust(poisson), na.action=na.omit,

The above SPlus command names the output file from this particular command as "test2", this will be the output from a GAM model of respiratory mortality for the age group of 75 and over. The model includes a *Loess* smooth of date, with a span of 0.0274, the day of the week is included as a factor, there is a *Loess* smooth of temperature lag 0 to lag 5, with a span of 0.9. The model also includes relative humidity lag 0 to lag 1. The final component is the pollution term which in this particular example is for lag 0 to lag 59. The dataset which the model will use is "dubthesis", and the data is treated as robust Poisson data. The final part of the command is to allow the model to run if there is some data missing. The above command is typical of the commands used in this study. When the task has been completed, the output in the form of the **beta**, **standard error**, and "**t**" is obtained by the following command;

> summary.glm(test2)

This is the command to get the GLM conponent of the output file "test2". An output like those presented in Appendix X would be obtained.

The other main commands used in SPlus were the command to get the autocorrelation function sum of the model, which was of the following form;

> sum(acf(residuals(test2), type="p")$acf)

This particular command would produce the sum of the partial autocorrelation functions for the output file "test2". This was used in the development of the model. Another command which was used in the model development was the *AIC* command which gave the AIC value for the model, it was simply;

>AIC(test2)

The above is a summary of the main SPlus commands used in the data analysis, there were numerous other commands used, but the above commands were the most frequently used in this work.

Appendix VII

COMPUTER OUTPUT FROM THE DEVELOPMENT OF THE ANALYSIS MODEL, UP TO THE INCLUSION OF THE TEMPERATURE TERM

Development of data analysis model

DATE

Taking a loess smooth of Date or trend and finding the min sum of the acf residuals of each model;

1) Span 0.5

```
lo(Date, 0.5) 0.0110595
> sum(acf(residuals),type="p")$acf)
Error in parse(text = txt): Syntax error: No opening parenthesis,
before ")" at this point:
sum(acf(residuals),type="p")$acf)
Dumped
➢ sum(acf(residuals(pgmod1),type="p")$acf)
➢
[1] 1.612665
```

2) Span 0.3

```
> fmod1_gam(formula=allmort~lo(Date,.3),
data=model595,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmod1),type="p")$acf)
[1] 1.602032
```

3) Span 0.1

```
fmod1_gam(formula=allmort~lo(Date,.1),
data=model595,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmod1),type="p")$acf)
[1] 1.526712
>
```

4) Span 0.05

```
> pgmod1_gam(formula=allmort~lo(Date,.05),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] 0.797407
```

5) Span 0.04

```
> pgmod1_gam(formula=allmort~lo(Date,.04),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] 0.5170473
```

6) Span 0.03

```
> pgmod1_gam(formula=allmort~lo(Date,.03),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] 0.1790597
```

7) Span 0.02

```
> pgmod1_gam(formula=allmort~lo(Date,.02),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] -0.2980223
```

8) Span 0.025

```
> pgmod1_gam(formula=allmort~lo(Date,.025),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] -0.03208279
```

9) Span 0.026

```
> pgmod1_gam(formula=allmort~lo(Date,.026),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] 0.01413569
```

10) Span 0.0255

```
> pgmod1_gam(formula=allmort~lo(Date,.0255),
+ data=x6mod1,family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod1),type="p")$acf)
[1] -0.000834371
```

This span of 0.0255 was chosen as the starting span to use in the model for the "Date" term or trend within the data.

WEEKDAY TERM

1) Include weekday as a factor, Date span of 0.0255, again find the min sum acf residuals

```
> pgmod2_gam(formula=allmort~lo(Date,.0255) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod2),type="p")$acf)
[1] -0.001801485
```

2) Span 0.026

```
> pgmod2_gam(formula=allmort~lo(Date,.026) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod2),type="p")$acf)
[1] 0.01363764
```

3) Span 0.0257

```
> pgmod2_gam(formula=allmort~lo(Date,.0257) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod2),type="p")$acf)
[1] -0.001666127
```

4) Span 0.0258

```
> pgmod2_gam(formula=allmort~lo(Date,.0258) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod2),type="p")$acf)
[1] -0.001666127
```

5) Span 0.0259

```
> pgmod2_gam(formula=allmort~lo(Date,.0259) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(pgmod2),type="p")$acf)
[1] 0.013504366) Span 0.0256
> pgmod2_gam(formula=allmort~lo(Date,.0256) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
sum(acf(residuals(pgmod2),type="p")$acf)
[1] -0.001801485
```

Output from model for day of week effect. Relative to a Monday

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday) ,
data=model595,family=robust(poisson), na.action=na.omit)
> summary.glm(fmodl)

Call: gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday), family =
robust(poisson), data =
     model595, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -3.078364 -0.7337394 -0.06442228 0.6166446 3.246693

Coefficients:
                      Value  Std. Error      t value
     (Intercept)  2.59683346 0.008701898  298.4215047
lo(Date, 0.0257) -1.20383402 0.258800078   -4.6515984
   factor(wday)2 -0.01240687 0.012340701   -1.0053616
   factor(wday)3 -0.01478670 0.012342056   -1.1980744
   factor(wday)4 -0.02082590 0.012376946   -1.6826365
   factor(wday)5 -0.01144504 0.012348250   -0.9268553
   factor(wday)6 -0.01736987 0.012362787   -1.4050123
   factor(wday)7 -0.03305279 0.012400591   -2.6654206

(Dispersion Parameter for Robust Poisson family taken to be 0.8556489 )

    Null Deviance: 7885.146 on 6118 degrees of freedom

Residual Deviance: 5975.223 on 6041.1251213 degrees of freedom
```

Commands for plots of the acf residuals

```
> win.graph()> pgmod2_gam(formula=allmort~lo(Date,.0255) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> plot(acf(residuals(pgmod2),type="p")$acf)
> pgmod2_gam(formula=allmort~lo(Date,.0257) + factor(wday),
+ data=x6mod1, family=robust(poisson), na.action=na.omit)
> plot(acf(residuals(pgmod2),type="p")$acf)
> win.graph()> plot(acf(residuals(pgmod2),type="p")$acf
```

Temperature

Temperature was introduced into the model, with lag 0 to lag 6 being investigated. The AIC value was used to determine the most suitable temperature lag to incorporate

Temp lag 0

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+
lo(tempmin,.7) , data=model595,family=robust(poisson),
na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin,
0.7), family = robust(
    poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.094
Residual Deviance =  6008.684
AIC= 6147.846
```

Temp lag 1

```
fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+ lo(tempmin1,.7)
, data=model595,family=robust(poisson), na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin1,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.101
Residual Deviance =  6005.801
AIC= 6145.299
```

Temp lag 2

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+
lo(tempmin2,.7) , data=model595,family=robust(poisson),
na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin2,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.101
Residual Deviance =  5999.402
AIC= 6138.558
```

Temp lag 3

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+
lo(tempmin3,.7) , data=model595,family=robust(poisson),
na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin3,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.099
Residual Deviance =  5982.773
AIC= 6120.941
```

Temp lag 4

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+
lo(tempmin4,.7) , data=model595,family=robust(poisson),
na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin4,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.096
Residual Deviance =  5969.397
```

AIC= 6106.964

Temp lag 5

```
fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+ lo(tempmin5,.7)
, data=model595,family=robust(poisson), na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin5,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.088
Residual Deviance =  5973.057
AIC= 6110.954
```

Temp lag 6

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+
factor(wday)+lo(tempmin6,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(tempmin6,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.093
Residual Deviance =  5977.262
AIC= 6115.407
```

Running averages of temperature

Temp lag 0-1

```
fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp01,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp01,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.045
Residual Deviance =  6011.914
AIC= 6151.375
```

Temp lag 0-2

```
fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp02,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp02,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.985
Residual Deviance =  6004.56
AIC= 6143.843
```

Temp lag 0-3

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp03,.7),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp03,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.948
Residual Deviance =  6000.432
```

```
AIC= 6139.591
```

Temp lag 0-4

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp04,.7),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp04,
0.7), family = robust(
    poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.916
Residual Deviance =  5997.607
AIC= 6136.737
```

Temp lag 0-5

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp05,.7),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.7), family = robust(
    poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.902
Residual Deviance =  5984.265
AIC= 6122.821
```

Temp lag 0-6

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp06,.7),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp06,
0.7), family = robust(
    poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
```

```
Degrees of Freedom Residual =  6038.892
Residual Deviance =  5985.412
AIC= 6124.02
```

Temp lag 2-3

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp23,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp23,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.049
Residual Deviance =  5989.751
AIC= 6128.429
```

Temp lag 1-5

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp15,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp15,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.916
Residual Deviance =  5990.393
AIC= 6129.526
```

Temp lag 2-5

```
> fmodl_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp25,.7),
+ data=model595, family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp25,
0.7), family = robust(
     poisson), data = model595, na.action = na.omit)
```

```
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.942
Residual Deviance =  5987.2
AIC= 6126.045
```

Having chosen temp lag 0-5, the optimum span for this has to be determined.

Span 0.8

```
fmodl_gam(formula=allmort~lo(Date,.0257) + factor(wday)+lo(temp05,.8),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.8), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.257
Residual Deviance =  5984.068
AIC= 6121.997
```

Span 0.9

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp05,.9),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9), family = robust(
     poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.519
Residual Deviance =  5983.081
AIC= 6120.501
```

No Span

```
> fmodl_gam(formula=allmort~lo(Date,.0257) + factor(wday)+temp05,
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + temp05,
family = robust(poisson), data
      = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6040.121
Residual Deviance =  5984.681
AIC= 6121.139
```

Span 0.85

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp05,.85),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.85), family = robust(
      poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.397
Residual Deviance =  5984.833
AIC= 6122.557
```

Span 0.95

```
> fmodl_gam(formula=allmort~lo(Date,.0257) +
factor(wday)+lo(temp05,.95),
+ data=model595,family=robust(poisson),na.action=na.omit)
> AIC(fmodl)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.95), family = robust(
      poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6039.638
Residual Deviance =  5985.028
```

AIC= 6122.344

Appendix VIII

COMPUTER OUTPUT FOR THE COMPLETION OF THE ANALYSIS MODEL

Relative Humidity

Using temp lag 0-5 with a span of 0.9, relative humidity at various lags will be checked with a span of 0.7

Relative humidity lag 0

```
> fmodlrh_gam(formula=allmort~lo(Date,.0257)+
factor(wday)+lo(temp05,.9) +lo(relhum,.7),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum, 0.7),
     family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6037.016
Residual Deviance =  5984.475
AIC= 6126.472
```

Relative humidity lag 1

```
fmodlrh_gam(formula=allmort~lo(Date,.0257)+ factor(wday)+lo(temp05,.9)
+lo(relhum1,.7),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum1, 0.7),
      family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6037.009
Residual Deviance =  5979.06
AIC= 6120.707
```

Relative humidity lag 2

```
> fmodlrh_gam(formula=allmort~lo(Date,.0257)+
factor(wday)+lo(temp05,.9) +lo(relhum2,.7),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum2, 0.7),
      family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6037.011
Residual Deviance =  5992.842
AIC= 6135.256
```

Relative humidity lag 1-2

```
> fmodlrh_gam(formula=allmort~lo(Date,.0257)+
factor(wday)+lo(temp05,.9) +lo(relhum12,.7),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum12, 0.7),
    family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6036.886
Residual Deviance =  5983.157
AIC= 6125.267
```

Relative humidity lag 0-1

```
> fmodlrh_gam(formula=allmort~lo(Date,.0257)+
factor(wday)+lo(temp05,.9) +lo(relhum01,.7),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum01, 0.7),
    family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6036.888
Residual Deviance =  5986.655
AIC= 6128.893
```

Checking the best span for relative humidity lag 0-1

Span 0.8

```
fmodlrh_gam(formula=allmort~lo(Date,.0257)+factor(wday)+lo(temp05,.9)+
lo(relhum01,.8),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum01, 0.8),
      family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total = 6119
Degrees of Freedom Residual =  6037.303
Residual Deviance =  5984.533
AIC= 6125.926
```

Span 0.9

```
fmodlrh_gam(formula=allmort~lo(Date,.0257)+factor(wday)+lo(temp05,.9)+
lo(relhum01,.9),
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + lo(relhum01, 0.9),
      family = robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6037.651
Residual Deviance =  5983.866
AIC= 6124.609
```

Span 1.0

```
fmodlrh_gam(formula=allmort~lo(Date,.0257)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> AIC(fmodlrh)
gam(formula = allmort ~ lo(Date, 0.0257) + factor(wday) + lo(temp05,
0.9) + relhum01, family =
    robust(poisson), data = model595, na.action = na.omit)
Degrees of Freedom Total =  6119
Degrees of Freedom Residual =  6038.52
Residual Deviance =  5983.674
```

AIC= 6122.885

Checking the span for data again, now that other elements have been included in the model.

Date span

Span 0.0257

```
fmodlrh_gam(formula=allmort~lo(Date,.0257)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmodlrh),type="p")$acf)
```

[1] -0.06699777

Span 0.027

```
> fmodlrh_gam(formula=allmort~lo(Date,.027)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmodlrh),type="p")$acf)
[1] -0.01785016
```

Span 0.028

```
> fmodlrh_gam(formula=allmort~lo(Date,.028)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmodlrh),type="p")$acf)
[1] 0.01775159
```

Span 0.0275

```
>
fmodlrh_gam(formula=allmort~lo(Date,.0275)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmodlrh),type="p")$acf)
[1] 0.006025849
```

Span 0.274

```
>
fmodlrh_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+
relhum01,
+ data=model595, family=robust(poisson), na.action=na.omit)
> sum(acf(residuals(fmodlrh),type="p")$acf)
[1] -0.005902874
```

Sensitivity analysis of model

Smoke included in model for sensitivity test

```
> sens_gam(formula=allmort~lo(Date,.0274) + factor(wday) +
lo(temp05,.9) +relhum01+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum0
1 +
     smk04, family = robust(poisson), data = DUBTHES, na.action =
na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q       Max
 -3.130595 -0.7372787 -0.05954415 0.6275945 2.971123
```

Coefficients:

	Value	Std. Error	t value
(Intercept)	2.455373619	0.0411725652	59.6361584
lo(Date, 0.0274)	-0.974310962	0.2775034995	-3.5109862
factor(wday)2	-0.011073363	0.0124854369	-0.8869023
factor(wday)3	-0.013373953	0.0124864309	-1.0710789
factor(wday)4	-0.019827965	0.0125208294	-1.5835984
factor(wday)5	-0.009856187	0.0124885176	-0.7892199
factor(wday)6	-0.017713051	0.0125064206	-1.4163166
factor(wday)7	-0.033071357	0.0125518196	-2.6347859
lo(temp05, 0.9)	-4.439609727	0.2933425952	-15.1345553
relhum01	0.001425608	0.0004945736	2.8824999
smk04	0.000617844	0.0001053840	5.8627898

(Dispersion Parameter for Robust Poisson family taken to be 0.866623)

Null Deviance: 7885.146 on 6118 degrees of freedom

Residual Deviance: 6000.323 on 6042.0731911 degrees of freedom

Number of Fisher Scoring Iterations: 4

Date span halved, span 0.0137

```
> sens_gam(formula=allmort~lo(Date,.0137) + factor(wday) +
lo(temp05,.9) +relhum01+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0137) + factor(wday) +
lo(temp05, 0.9) + relhum0
1 +
```

```
    smk04, family = robust(poisson), data = DUBTHES, na.action =
na.omit)
Deviance Residuals:
      Min       1Q   Median       3Q      Max
 -3.135868 -0.7134383 -0.06525745 0.6197556 2.919627
Coefficients:
                        Value  Std. Error    t value
     (Intercept)  2.4746975769 0.0405775081  60.9869283
lo(Date, 0.0137) -1.0045421443 0.2739241665  -3.6672272
   factor(wday)2 -0.0116818143 0.0123135329  -0.9486972
   factor(wday)3 -0.0140444580 0.0123119011  -1.1407221
   factor(wday)4 -0.0201231875 0.0123496534  -1.6294536
   factor(wday)5 -0.0106634347 0.0123186286  -0.8656349
   factor(wday)6 -0.0160127529 0.0123217536  -1.2995515
   factor(wday)7 -0.0329050695 0.0123769051  -2.6585862
 lo(temp05, 0.9) -3.8531116902 0.2891320417 -13.3264776
        relhum01  0.0012574973 0.0004874816   2.5795791
           smk04  0.0005366222 0.0001031179   5.2039667

(Dispersion Parameter for Robust Poisson family taken to be 0.8438613 )
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 5753.943 on 5966.9388959 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Date span doubled, 0.055

```
> sens_gam(formula=allmort~lo(Date,.055) + factor(wday) + lo(temp05,.9)
+relhum01+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.055) + factor(wday) +
lo(temp05, 0.9) + relhum01 +
    smk04, family = robust(poisson), data = DUBTHES, na.action =
na.omit)
Deviance Residuals:
      Min       1Q      Median        3Q      Max
 -3.207942 -0.7568907 -0.06975561 0.6378135 3.165384
Coefficients:
                        Value   Std. Error     t value
    (Intercept)  2.4163003148 0.0417866215  57.8247349
lo(Date, 0.055) -1.0012246278 0.2813739793  -3.5583412
  factor(wday)2 -0.0105792473 0.0126582295  -0.8357604
  factor(wday)3 -0.0129933910 0.0126602882  -1.0263108
  factor(wday)4 -0.0201279160 0.0126965153  -1.5853103
  factor(wday)5 -0.0096385258 0.0126632108  -0.7611439
  factor(wday)6 -0.0193359958 0.0126845452  -1.5243744
  factor(wday)7 -0.0333156725 0.0127261814  -2.6178845
lo(temp05, 0.9) -5.8790980977 0.2978022746 -19.7416158
      relhum01  0.0018610884 0.0005020462   3.7070061
         smk04  0.0006560632 0.0001069636   6.1335162

(Dispersion Parameter for Robust Poisson family taken to be 0.8973106 )
Null Deviance: 7885.146 on 6118 degrees of freedom
```

```
Residual Deviance: 6259.724 on 6076.1593133 degrees of freedom
Number of Fisher Scoring Iterations: 3
```

Origional date span, 0.0274. No weekday term

```
> sens_gam(formula=allmort~lo(Date,.0274) + lo(temp05,.9)
+relhum01+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0274) + lo(temp05, 0.9) +
relhum01 + smk04, fami
ly =
    robust(poisson), data = DUBTHES, na.action = na.omit)
Deviance Residuals:
      Min        1Q      Median        3Q       Max
 -3.152539 -0.739836 -0.06139111 0.6290454 3.003253
Coefficients:
                      Value   Std. Error    t value
    (Intercept)  2.4416289543 0.0403668764  60.485952
lo(Date, 0.0274) -0.9748103581 0.2774749899  -3.513147
 lo(temp05, 0.9) -4.4402994988 0.2933439344 -15.136838
        relhum01  0.0014115744 0.0004945581   2.854214
          smk04  0.0006113899 0.0001053446   5.803714

(Dispersion Parameter for Robust Poisson family taken to be 0.8664761 )
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6005.452 on 6048.0737203 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Origional model, no temperature term

```
> sens_gam(formula=allmort~lo(Date,.0274) +factor(wday)
+relhum01+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
relhum01 + smk04, family
=
    robust(poisson), data = DUBTHES, na.action = na.omit)
Deviance Residuals:
      Min       1Q      Median      3Q     Max
 -3.074148 -0.7330191 -0.06230303 0.6262512 2.970494
Coefficients:
                        Value    Std. Error    t value
     (Intercept)  2.518969837 0.04101680703  61.4131138
lo(Date, 0.0274) -0.516384875 0.27344505387  -1.8884411
   factor(wday)2 -0.012127933 0.01244880984  -0.9742243
   factor(wday)3 -0.014216666 0.01245021000  -1.1418816
   factor(wday)4 -0.020449016 0.01248295306  -1.6381553
   factor(wday)5 -0.012147772 0.01245471185  -0.9753555
   factor(wday)6 -0.018794449 0.01247122537  -1.5070251
   factor(wday)7 -0.033714645 0.01251222789  -2.6945357
       relhum01  0.000578093 0.00049316268   1.1722156
          smk04  0.001025554 0.00009313577  11.0113859

(Dispersion Parameter for Robust Poisson family taken to be 0.8624833 )
Null Deviance: 7885.146 on 6118 degrees of freedom
```

```
Residual Deviance: 5983.279 on 6043.6818467 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Original model, no relative humidity term

```
> sens_gam(formula=allmort~lo(Date,.0274) +factor(wday)
+lo(temp05,.9)+smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + smk04,
    family = robust(poisson), data = DUBTHES, na.action = na.omit)
Deviance Residuals:
     Min       1Q      Median        3Q     Max
 -3.12546 -0.7365217 -0.05727145 0.6250285 2.97918
Coefficients:
                      Value   Std. Error      t value
     (Intercept)  2.57087150 0.0092653110  277.4727703
lo(Date, 0.0274) -0.82852880 0.2744061515   -3.0193521
   factor(wday)2 -0.01079329 0.0125086662   -0.8628649
   factor(wday)3 -0.01313651 0.0125102498   -1.0500595
   factor(wday)4 -0.01959978 0.0125436597   -1.5625251
   factor(wday)5 -0.01007261 0.0125117206   -0.8050543
   factor(wday)6 -0.01763770 0.0125292261   -1.4077245
   factor(wday)7 -0.03266444 0.0125740560   -2.5977646
 lo(temp05, 0.9) -4.08395487 0.2937498525  -13.9028321
          smk04  0.00065282 0.0001051363    6.2092741
```

(Dispersion Parameter for Robust Poisson family taken to be 0.8693622

Null Deviance: 7885.146 on 6118 degrees of freedom

Residual Deviance: 6004.36 on 6043.0730116 degrees of freedom

Number of Fisher Scoring Iterations: 5

Original model, no temperature, no humidity and no weekday terms

```
> sens_gam(formula=allmort~lo(Date,.0274) +smk04,
+ data=DUBTHES, family=robust(poisson), na.action=na.omit)
> summary.glm(sens)

Call: gam(formula = allmort ~ lo(Date, 0.0274) + smk04, family =
robust(poisson), data =
     DUBTHES, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -3.095973 -0.7316177 -0.06185491 0.6287211 2.992936
Coefficients:
                      Value    Std. Error     t value
     (Intercept)  2.550063164 0.00427814891  596.066948
lo(Date, 0.0274) -0.464447072 0.26985964403   -1.721069
           smk04  0.001030703 0.00009242912   11.151285

(Dispersion Parameter for Robust Poisson family taken to be 0.8635261 )
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 5992.245 on 6050.6818437 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Appendix IX

COMPUTER OUTPUTS FROM DATA ANALYSIS FOR SMOKE AND SO_2

Based on all mortality

Smoke lag 0

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +Smoke,data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05)  + relhum01 + Smoke, family = robust(poisson), data =
smkmod96, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -3.144033 -0.7409884 -0.0631379 0.6298099 3.000114
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  2.4507772391 0.0410617818  59.6851167
lo(Date, 0.0274) -1.2534182998 0.2725695299  -4.5985268
   factor(wday)2 -0.0113417705 0.0124944387  -0.9077455
   factor(wday)3 -0.0143197126 0.0124991168  -1.1456580
   factor(wday)4 -0.0203932627 0.0125327856  -1.6271931
   factor(wday)5 -0.0094893863 0.0124994339  -0.7591853
   factor(wday)6 -0.0172920082 0.0125171401  -1.3814664
   factor(wday)7 -0.0315200248 0.0125628748  -2.5089818
      lo(temp05) -4.9346129116 0.2810306616 -17.5589841
        relhum01  0.0016046982 0.0004934602   3.2519301
           Smoke  0.0002523076 0.0000799330   3.1564890(Dispersion
Parameter for Robust Poisson family taken to be 0.8681189 )
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6009.219 on 6040.3477584 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

smoke lag 1>

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag1, + data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag1, family = robust
(
      poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -3.140625 -0.736117 -0.06163841 0.6271926 2.970197
Coefficients:
                         Value    Std. Error     t value
     (Intercept)  2.4619747628 0.04112680696  59.8630174
lo(Date, 0.0274) -1.1485571542 0.27283649569  -4.2096903
   factor(wday)2 -0.0124116152 0.01249780205  -0.9931038
   factor(wday)3 -0.0149230471 0.01249927620  -1.1939129
   factor(wday)4 -0.0222047510 0.01254284537  -1.7703121
   factor(wday)5 -0.0111620119 0.01250698882  -0.8924620
   factor(wday)6 -0.0191621747 0.01252545559  -1.5298585
   factor(wday)7 -0.0343150866 0.01256844739  -2.7302566
      lo(temp05) -4.7486114796 0.28207340947 -16.8346654
       relhum01  0.0014416295 0.00049470944   2.9140933
         smlag1  0.0003815515 0.00007924965   4.8145514(Dispersion
Parameter for Robust Poisson family taken to be 0.8685269 )    Null
Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6006.469 on 6040.3423767 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

smoke lag 2>

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag2,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag2, family = robust(
    poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q      Max
 -3.136419 -0.7372471 -0.06282434 0.6273199 2.957563
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4483340073 0.0410315521  59.6695440
lo(Date, 0.0274) -1.2392031337 0.2724060423  -4.5491030
   factor(wday)2 -0.0096616788 0.0124980078  -0.7730575
   factor(wday)3 -0.0128355048 0.0124928118  -1.0274312
   factor(wday)4 -0.0195484241 0.0125244989  -1.5608149
   factor(wday)5 -0.0091905976 0.0124911707  -0.7357675
   factor(wday)6 -0.0166191152 0.0125088126  -1.3285925
   factor(wday)7 -0.0326288253 0.0125549782  -2.5988755
      lo(temp05) -4.8993166332 0.2818248455 -17.3842609
        relhum01  0.0016179416 0.0004930319   3.2816166
          smlag2  0.0002822957 0.0000802772   3.5165115
(Dispersion Parameter for Robust Poisson family taken to be 0.8668463)
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6004.86 on 6040.3469713 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

smoke lag 3

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag3,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag3, family = robust(poisson), data =
smkmod96, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -3.136657 -0.7387166 -0.06070918 0.6295038 2.982357
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  2.444176023 0.0410144076  59.5931080
lo(Date, 0.0274) -1.293059808 0.2720949993  -4.7522366
   factor(wday)2 -0.010801531 0.0124870094  -0.8650215
   factor(wday)3 -0.012219110 0.0124972271  -0.9777457
   factor(wday)4 -0.019039085 0.0125242339  -1.5201796
   factor(wday)5 -0.008667297 0.0124884467  -0.6940252
   factor(wday)6 -0.016502577 0.0125057461  -1.3195995
   factor(wday)7 -0.032382906 0.0125509795  -2.5801099
      lo(temp05) -4.990534689 0.2812959117 -17.7412272
        relhum01  0.001691796 0.0004922323   3.4369865
         smlag3  0.000206447 0.0000796283   2.5926331
(Dispersion Parameter for Robust Poisson family taken to be 0.8662851
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6004.724 on 6040.3499286 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

smoke lag 4

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag4,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag4, family = robust(
      poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -3.144056 -0.7411668 -0.06257531 0.6248651 3.041304
Coefficients:
                         Value    Std. Error     t value
     (Intercept)  2.4417090748 0.04105977323  59.4671836
lo(Date, 0.0274) -1.2277596493 0.27217681480  -4.5108899
   factor(wday)2 -0.0115751080 0.01249772145  -0.9261775
   factor(wday)3 -0.0138524685 0.01249984109  -1.1082116
   factor(wday)4 -0.0183760984 0.01254254318  -1.4651015
   factor(wday)5 -0.0081297713 0.01250060488  -0.6503502
   factor(wday)6 -0.0161095379 0.01251548207  -1.2871688
   factor(wday)7 -0.0329792122 0.01256274859  -2.6251590
      lo(temp05) -4.9015983916 0.28078103409 -17.4570138
        relhum01  0.0016924602 0.00049253732   3.4362071
          smlag4  0.0003037164 0.00007849607   3.8691927
```

smoke lag 5>

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag5,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag5, family = robust(
      poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median          3Q     Max
 -3.138808 -0.7411783 -0.06440238 0.6281412 3.0224
Coefficients:
                          Value    Std. Error     t value
     (Intercept)  2.4411213961 0.04101098771  59.5235943
lo(Date, 0.0274) -1.2492211886 0.27172617988  -4.5973531
   factor(wday)2 -0.0113855007 0.01248440529  -0.9119778
   factor(wday)3 -0.0137017488 0.01248463597  -1.0974889
   factor(wday)4 -0.0199079802 0.01251907032  -1.5902124
   factor(wday)5 -0.0072571796 0.01249401068  -0.5808527
   factor(wday)6 -0.0157294581 0.01250729469  -1.2576227
   factor(wday)7 -0.0322621728 0.01254778426  -2.5711450
     lo(temp05) -4.9742358526 0.27880391163 -17.8413417
        relhum01  0.0017095391 0.00049182520   3.4759079
          smlag5  0.0002670179 0.00007804691   3.4212491
(Dispersion Parameter for Robust Poisson family taken to be 0.866175 )
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6002.883 on 6040.3515118 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

smoke lag 6

```
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smlag6,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smlag6, family = robust
(
      poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -3.145059 -0.7393167 -0.06084179 0.6279858 2.989937
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  2.4424227745 0.0410514810  59.4965812
lo(Date, 0.0274) -1.1977961611 0.2719182926  -4.4049856
   factor(wday)2 -0.0126439209 0.0124961801  -1.0118229
   factor(wday)3 -0.0147785095 0.0124955784  -1.1826991
   factor(wday)4 -0.0209455446 0.0125309132  -1.6715098
   factor(wday)5 -0.0096196502 0.0124977239  -0.7697122
   factor(wday)6 -0.0156762600 0.0125196529  -1.2521322
   factor(wday)7 -0.0324320559 0.0125601765  -2.5821338
      lo(temp05) -4.9727192687 0.2768891374 -17.9592429
        relhum01  0.0016819433 0.0004923949   3.4158422
          smlag6  0.0003332322 0.0000770478   4.3250063
(Dispersion Parameter for Robust Poisson family taken to be 0.8687398 )
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6009.213 on 6040.35088 degrees of freedom
```

smoke lag 0 to lag 6 estimated simultaneously

```
mod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum0
1 +Smoke+smlag6
+ +smlag1 +smlag2+smlag3 +smlag4 +smlag5,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + Smoke + smlag6 + smlag1 +
      smlag2 + smlag3 + smlag4 + smlag5, family = robust(poisson), data
= smkmod96, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -3.134722 -0.736765 -0.0589409 0.626829 2.915405
```

Coefficients:

	Value	Std. Error	t value
(Intercept)	2.45756750600	0.0411483094	59.7246288
lo(Date, 0.0274)	-0.80592834078	0.2803153044	-2.8750779
factor(wday)2	-0.01350368444	0.0125283264	-1.0778522
factor(wday)3	-0.01631728597	0.0125243990	-1.3028398
factor(wday)4	-0.02165985993	0.0125675541	-1.7234746
factor(wday)5	-0.01105325743	0.0125326625	-0.8819560
factor(wday)6	-0.01771721609	0.0125378831	-1.4130947
factor(wday)7	-0.03422357427	0.0125907558	-2.7181509
lo(temp05)	-4.33986079055	0.2967959356	-14.6223727
relhum01	0.00134199370	0.0004948327	2.7120149
Smoke	0.00005234563	0.0001078476	0.4853666
smlag6	0.00027949019	0.0001070239	2.6114747
smlag1	0.00030059198	0.0001321528	2.2745798
smlag2	0.00007477155	0.0001358410	0.5504345
smlag3	-0.00008511330	0.0001348963	-0.6309537
smlag4	0.00026852973	0.0001332013	2.0159698
smlag5	-0.00004662354	0.0001331425	-0.3501777

(Dispersion Parameter for Robust Poisson family taken to be 0.8686911)

Null Deviance: 7885.146 on 6118 degrees of freedom

Residual Deviance: 5996.755 on 6034.3381123 degrees of freedom

Number of Fisher Scoring Iterations: 4

Investigation of 3 day and 5 day running averages of smoke exposure

All mortality, smoke average 3 day (lag 0 to lag 2 inclusive)>

```
mod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum0
1 +smk02,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smk02, family = robust(
    poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
     Min          1Q      Median          3Q      Max
 -3.13907 -0.7355647 -0.0618281 0.6258541 2.971891
Coefficients:              Value     Std. Error     t value
     (Intercept)  2.4586079288 0.04108607550  59.8404179
lo(Date, 0.0274) -1.0693894133 0.27573299704  -3.8783512
   factor(wday)2 -0.0110195372 0.01249445492  -0.8819542
   factor(wday)3 -0.0143038667 0.01249638912  -1.1446400
   factor(wday)4 -0.0210892279 0.01253427569  -1.6825247
   factor(wday)5 -0.0105114176 0.01250187000  -0.8407876
   factor(wday)6 -0.0182830324 0.01251940612  -1.4603754
   factor(wday)7 -0.0327581107 0.01256115243  -2.6078905
      lo(temp05) -4.6372384191 0.28839210673 -16.0796302
        relhum01  0.0014354429 0.00049455203   2.9025113
           smk02  0.0004934382 0.00009421785   5.2372053
```

```
(Dispersion Parameter for Robust Poisson family taken to be 0.8684316 )
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6005.915 on 6040.3401474 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

All mortality, smoke average 5 day (lag 0 to lag 4 inclusive)

```
>
fmod3_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp05)+relhum
01 +smk04,
+ data=smkmod96,family=robust(poisson),na.action=na.omit)
> summary.glm(fmod3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05) + relhum01 + smk04, family = robust(
     poisson), data = smkmod96, na.action = na.omit)
Deviance Residuals:
      Min          1Q     Median          3Q         Max
 -3.135035 -0.7372936 -0.060309 0.6266887 2.967424
```

Coefficients:

	Value	Std. Error	t value
(Intercept)	2.4543823029	0.0410474698	59.7937537
lo(Date, 0.0274)	-0.9711413695	0.2780784280	-3.4923290
factor(wday)2	-0.0111983441	0.0124913513	-0.8964878
factor(wday)3	-0.0135688957	0.0124928013	-1.0861372
factor(wday)4	-0.0198689835	0.0125265421	-1.5861507
factor(wday)5	-0.0098917226	0.0124942575	-0.7917015
factor(wday)6	-0.0177717407	0.0125122076	-1.4203521
factor(wday)7	-0.0330208446	0.0125576265	-2.6295450
lo(temp05)	-4.4929620264	0.2937693606	-15.2941819
relhum01	0.0014369628	0.0004940502	2.9085364
smk04	0.0006295212	0.0001054793	5.9681975

(Dispersion Parameter for Robust Poisson family taken to be 0.8678704)

Null Deviance: 7885.146 on 6118 degrees of freedom

Residual Deviance: 6002.481 on 6040.340245 degrees of freedom

Number of Fisher Scoring Iterations: 4

SULPHUR DIOXIDE

LAG 0

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+SO2,+ data=so2lag96a, family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + SO2,    family = robust(poisson), data =
so2lag96a, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median        3Q       Max
 -3.139298 -0.7396294 -0.06404389 0.632127 2.996592
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.426629089 0.0410911645  59.0547657
lo(Date, 0.0274) -0.978184529 0.3252552518  -3.0074365
   factor(wday)2 -0.011771229 0.0124895024  -0.9424898
   factor(wday)3 -0.014918428 0.0124999838  -1.1934758
   factor(wday)4 -0.021910404 0.0125487912  -1.7460171
   factor(wday)5 -0.010127998 0.0124985855  -0.8103315
   factor(wday)6 -0.016315720 0.0125041827  -1.3048210
   factor(wday)7 -0.030951090 0.0125771356  -2.4609013
 lo(temp04, 0.9) -5.003690038 0.2714713686 -18.4317413
       relhum01  0.001746650 0.0004946675   3.5309578
            SO2  0.000581172 0.0002228885   2.6074560
(Dispersion Parameter for Robust Poisson family taken to be 0.8659248
    Null Deviance: 7882.838 on 6117 degrees of freedom
Residual Deviance: 6002.498 on 6041.0988938 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

LAG 1

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag1,
+ data=so2lag96a, family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag1,
    family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
      Min       1Q     Median       3Q      Max
 -3.134484 -0.739763 -0.06321547 0.6290853 2.997317
Coefficients:
                      Value   Std. Error    t value
    (Intercept)  2.4271422656 0.0410566829  59.1168623
lo(Date, 0.0274) -0.9731945025 0.3256558838  -2.9884137
   factor(wday)2 -0.0123540445 0.0125107243  -0.9874764
   factor(wday)3 -0.0157220437 0.0125399023  -1.2537613
   factor(wday)4 -0.0229810486 0.0126026000  -1.8235165
   factor(wday)5 -0.0124057906 0.0125961250  -0.9848894
   factor(wday)6 -0.0196536991 0.0125813124  -1.5621342
   factor(wday)7 -0.0334884587 0.0125702783  -2.6640984
 lo(temp04, 0.9) -5.0073047405 0.2715565936 -18.4392678
        relhum01  0.0017567229 0.0004946655   3.5513351
         so2lag1  0.0005883795 0.0002237153   2.6300364
(Dispersion Parameter for Robust Poisson family taken to be 0.8659539)
Null Deviance: 7884.558 on 6117 degrees of freedom
Residual Deviance: 6004.293 on 6041.0983562 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 2

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag2, + data=so2lag96a,
family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag2, family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -3.138404 -0.7403431 -0.0626806 0.6288652 2.998618
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4247151589 0.0411170305  58.9710670
lo(Date, 0.0274) -0.9577479398 0.3254383269  -2.9429476
   factor(wday)2 -0.0089080546 0.0125156910  -0.7117509
   factor(wday)3 -0.0135569847 0.0124947025  -1.0850186
   factor(wday)4 -0.0210972398 0.0125377767  -1.6826939
   factor(wday)5 -0.0106592346 0.0125162148  -0.8516340
   factor(wday)6 -0.0190881209 0.0125488928  -1.5211000
   factor(wday)7 -0.0342676577 0.0125770918  -2.7246090
 lo(temp04, 0.9) -5.0131218421 0.2712045323 -18.4846536
        relhum01  0.0017623503 0.0004948680   3.5612531
         so2lag2  0.0006106887 0.0002228481   2.7403804
(Dispersion Parameter for Robust Poisson family taken to be 0.8674466 )
Null Deviance: 7884.335 on 6117 degrees of freedom
Residual Deviance: 6008.814 on 6041.0955285 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 3

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag3,
+ data=so2lag96a, family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag3,  family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -3.135238 -0.7399047 -0.06121209 0.6265143 2.993853
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4216375759 0.0411562106  58.8401492
lo(Date, 0.0274) -0.9042979239 0.3241372371  -2.7898613
   factor(wday)2 -0.0085662741 0.0125088699  -0.6848160
   factor(wday)3 -0.0088522921 0.0125652331  -0.7045068
   factor(wday)4 -0.0178784464 0.0125417107  -1.4255190
   factor(wday)5 -0.0081370691 0.0124923958  -0.6513618
   factor(wday)6 -0.0164085891 0.0125088699  -1.3117563
   factor(wday)7 -0.0331750020 0.0125571292  -2.6419257
 lo(temp04, 0.9) -4.9996927462 0.2706859654 -18.4704543
       relhum01  0.0017481656 0.0004944906   3.5352860
        so2lag3  0.0006752959 0.0002199463   3.0702761
(Dispersion Parameter for Robust Poisson family taken to be 0.8669347 )
    Null Deviance: 7880.29 on 6117 degrees of freedom
Residual Deviance: 6005.147 on 6041.0990648 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 4

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag4,+ data=so2lag96a,
family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag4,  family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q      Max
 -3.138043 -0.7430781 -0.06151043 0.6267365 3:026721
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4090098302 0.0412033612  58.4663426
lo(Date, 0.0274) -0.6870035599 0.3238690922  -2.1212384
   factor(wday)2 -0.0100821031 0.0124933217  -0.8069994
   factor(wday)3 -0.0097841586 0.0125273887  -0.7810214
   factor(wday)4 -0.0129361649 0.0126342883  -1.0238934
   factor(wday)5 -0.0050635952 0.0125217878  -0.4043828
   factor(wday)6 -0.0144784664 0.0125169681  -1.1567071
   factor(wday)7 -0.0316219991 0.0125545608  -2.5187659
 lo(temp04, 0.9) -4.9608321275 0.2701379337 -18.3640708
        relhum01  0.0017750852 0.0004943034   3.5910842
         so2lag4  0.0009456081 0.0002188624   4.3205599
(Dispersion Parameter for Robust Poisson family taken to be 0.8672844)
    Null Deviance: 7884.335 on 6117 degrees of freedom
Residual Deviance: 6005.836 on 6041.0973044 degrees of freedom
Number of Fisher Scoring Iterations:
```

4lag 5

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag5,
+ data=so2lag96a, family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag5,family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -3.146993 -0.7422951 -0.06244548 0.6276647 3:026326
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4185991374 0.0412659136  58.6100955
lo(Date, 0.0274) -0.8704894403 0.3239020003  -2.6875087
   factor(wday)2 -0.0120752188 0.0125074732  -0.9654403
   factor(wday)3 -0.0136863030 0.0125042061  -1.0945359
   factor(wday)4 -0.0179577824 0.0125613617  -1.4296047
   factor(wday)5 -0.0050348198 0.0125842331  -0.4000895
   factor(wday)6 -0.0147115101 0.0125411116  -1.1730627
   factor(wday)7 -0.0319508817 0.0125703474  -2.5417660
 lo(temp04, 0.9) -5.0432555232 0.2696230538 -18.7048379
        relhum01  0.0017732796 0.0004947912   3.5838944
         so2lag5  0.0007104644 0.0002187136   3.2483776
(Dispersion Parameter for Robust Poisson family taken to be 0.8700473
    Null Deviance: 7884.89 on 6117 degrees of freedom
Residual Deviance: 6015.335 on 6041.0984617 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 6

```
sulphur_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+r
elhum01+so2lag6,
+ data=so2lag96a, family=robust(poisson),na.action=na.omit)
> summary.glm(sulphur)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so2l
ag6,family = robust(poisson), data = so2lag96a, na.action = na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q      Max
 -3.147501 -0.7410111 -0.06477094 0.6235183 3:004806
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  2.4229585188 0.0412366696  58.7573765
lo(Date, 0.0274) -0.9585584054 0.3241257714  -2.9573656
   factor(wday)2 -0.0120437062 0.0125133485  -0.9624687
   factor(wday)3 -0.0148965452 0.0125181981  -1.1899912
   factor(wday)4 -0.0206011440 0.0125472975  -1.6418790
   factor(wday)5 -0.0076945198 0.0125222481  -0.6144679
   factor(wday)6 -0.0134482189 0.0125851401  -1.0685792
   factor(wday)7 -0.0313368516 0.0125824003  -2.4905305
 lo(temp04, 0.9) -5.0979778262 0.2686937145 -18.9731935
       relhum01  0.0017717078 0.0004951383   3.5782079
        so2lag6  0.0006059972 0.0002188003   2.7696362
```

SIMULTANEOUS ESTIMATE OF SMOKE AND SO_2

SO_2 lag 0 to lag 2

```
both_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+relh
um01+so202, data=dubthesis,family=robust(poisson),na.action=na.omit)
> summary.glm(both)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so202,family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -3.136825 -0.7417048 -0.06362775 0.6294773 3.000443
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.4195916608 0.0411064463  58.8616112
lo(Date, 0.0274) -0.7599019751 0.3389932627  -2.2416433
   factor(wday)2 -0.0114298489 0.0124896620  -0.9151448
   factor(wday)3 -0.0155398171 0.0125065178  -1.2425375
   factor(wday)4 -0.0231956285 0.0125653276  -1.8460027
   factor(wday)5 -0.0122794564 0.0125377074  -0.9794021
   factor(wday)6 -0.0193433891 0.0125351570  -1.5431310
   factor(wday)7 -0.0330078315 0.0125552383  -2.6290088
 lo(temp04, 0.9) -4.9347680428 0.2731880028 -18.0636338
        relhum01  0.0017392035 0.0004955737   3.5094748
           so202  0.0008483034 0.0002495723   3.3990288
(Dispersion Parameter for Robust Poisson family taken to be 0.866707)
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6006.475 on 6042.0745694 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

SO_2 lag 0 to lag 4

```
both_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+relh
um01+so204,
+ data=dubthesis,family=robust(poisson),na.action=na.omit)
> summary.glm(both)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp04, 0.9) + relhum01 + so204,
      family = robust(poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -3.131775 -0.7430901 -0.06108851 0.6304271 3:003703
Coefficients:
                      Value   Std. Error     t value
     (Intercept)  2.406991034 0.0411442397  58.5012884
lo(Date, 0.0274) -0.467887378 0.3471280556  -1.3478812
   factor(wday)2 -0.010342356 0.0124843355  -0.8284267
   factor(wday)3 -0.012883992 0.0124845174  -1.0319976
   factor(wday)4 -0.020356890 0.0125193701  -1.6260315
   factor(wday)5 -0.010618448 0.0124923950  -0.8499930
   factor(wday)6 -0.018408006 0.0125097752  -1.4714897
   factor(wday)7 -0.033034348 0.0125490171  -2.6324251
 lo(temp04, 0.9) -4.854377952 0.2736344148 -17.7403780
        relhum01  0.001730708 0.0004956488   3.4918027
           so204  0.001203972 0.0002646091   4.5500037
(Dispersion Parameter for Robust Poisson family taken to be 0.8659199
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6002.563 on 6042.0731057 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

SO_2 and Smoke both lag 0 to lag 4

```
both_gam(formula=allmort~lo(Date,.0274)+factor(wday)+lo(temp04,.9)+relh
um01+so204+smk05,
+ data=dubthesis,family=robust(poisson),na.action=na.omit)
➢ summary.glm(both)
➢ Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
   lo(temp04, 0.9) + relhum01 + so204 + smk05, family
       = robust(poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
      Min        1Q      Median        3Q       Max
 -3.130891 -0.737157 -0.05937077 0.628101 2.971544
Coefficients:
                          Value   Std. Error      t value
     (Intercept)  2.45458568000 0.0413456419  59.36745856
lo(Date, 0.0274) -0.99292415878 0.3517437886  -2.82286196
   factor(wday)2 -0.01108987335 0.0124872133  -0.88809834
   factor(wday)3 -0.01336711571 0.0124881270  -1.07038595
   factor(wday)4 -0.01984761986 0.0125219632  -1.58502461
   factor(wday)5 -0.00985510156 0.0124961409  -0.78865160
   factor(wday)6 -0.01769362730 0.0125127239  -1.41405081
   factor(wday)7 -0.03308542174 0.0125530066  -2.63565716
 lo(temp04, 0.9) -4.43741302697 0.2934195898 -15.12309737
       relhum01  0.00144313421 0.0004958909   2.91018480
          so204 -0.00001374169 0.0003290752  -0.04175851
          smk05  0.00062131008 0.0001322578   4.69771914
(Dispersion Parameter for Robust Poisson family taken to be 0.8667082
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6000.109 on 6041.0733002 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Analysis output of 5 day moving average of smoke exposure

by age group and cause of death subgroups

all mortality

```
> fanal2_gam(formula=allmort~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,+ data=dubthesis,
family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -3.131035 -0.7374004 -0.05941052 0.6278033 2.971937
Coefficients:              Value   Std. Error     t value
     (Intercept)  2.4534635528 0.0410242052  59.8052672
lo(Date, 0.0274) -0.9860151396 0.2779280450  -3.5477353
   factor(wday)2 -0.0110843536 0.0124852996  -0.8877924
   factor(wday)3 -0.0133666594 0.0124862281  -1.0705122
   factor(wday)4 -0.0198595201 0.0125205955  -1.5861482
   factor(wday)5 -0.0098688457 0.0124882861  -0.7902482
   factor(wday)6 -0.0177063739 0.0125062621  -1.4158006
   factor(wday)7 -0.0330909449 0.0125516940  -2.6363728
 lo(temp05, 0.9) -4.4409236064 0.2933564484 -15.1383194
       relhum01  0.0014529025 0.0004937657   2.9424937
          smk04  0.0006164465 0.0001053855   5.8494448
(Dispersion Parameter for Robust Poisson family taken to be 0.8665978
Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6000.236 on 6042.0732405 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 0-64

```
> fanal2_gam(formula=all064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = rob
ust(
      poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -2.553759 -0.7398674 -0.06158502 0.577148 3.308877
Coefficients:
                        Value  Std. Error     t value
     (Intercept)  1.0428414137 0.085279855  12.2284614
lo(Date, 0.0274) -9.2461749386 0.565731390 -16.3437545
   factor(wday)2 -0.0098899477 0.025764528  -0.3838591
   factor(wday)3 -0.0248111256 0.025858896  -0.9594812
   factor(wday)4 -0.0154226636 0.025816611  -0.5973930
   factor(wday)5 -0.0250210611 0.025882410  -0.9667207
   factor(wday)6  0.0219980039 0.025578547   0.8600177
   factor(wday)7 -0.0486148742 0.026055950  -1.8657878
 lo(temp05, 0.9) -2.5597201435 0.607496162  -4.2135577
        relhum01  0.0009227685 0.001027887   0.8977331
           smk04  0.0002245784 0.000224712   0.9994052
(Dispersion Parameter for Robust Poisson family taken to be 0.8652775 )
    Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6340.753 on 6042.1154748 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 65-74

```
> fanal2_gam(formula=all6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9)+relhum01 +smk04,+ data=dubthesis,
family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -2.633116 -0.7656357 -0.1001019 0.5899127 3.008496
Coefficients:
                      Value   Std. Error     t value
     (Intercept)  1.142041146 0.0783201550  14.5817018
lo(Date, 0.0274) -3.742540951 0.5282181824  -7.0852180
   factor(wday)2  0.010787567 0.0236879469   0.4554032
   factor(wday)3  0.002810962 0.0237319483   0.1184463
   factor(wday)4 -0.021786031 0.0238587611  -0.9131250
   factor(wday)5  0.003973485 0.0236959622   0.1676861
   factor(wday)6 -0.026967306 0.0238578285  -1.1303336
   factor(wday)7 -0.039643904 0.0239646727  -1.6542644
 lo(temp05, 0.9) -5.653486421 0.5586162146 -10.1205197
        relhum01  0.001374577 0.0009432068   1.4573438
           smk04  0.000594421 0.0001966959   3.0220310
(Dispersion Parameter for Robust Poisson family taken to be 0.851153 )
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6131.555 on 6042.0478652 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 75+

```
> fanal2_gam(formula=all75~lo(Date,.0274) + factor(wday)+ lo(temp05,.9)
+relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust( poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -2.932908 -0.7681118 -0.06042421 0.6211036 2.862373
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.7395925167 0.0572136913  30.405179
lo(Date, 0.0274)  4.3554862419 0.3937232704  11.062303
   factor(wday)2 -0.0345770932 0.0174783153  -1.978285
   factor(wday)3 -0.0223677412 0.0174203743  -1.283999
   factor(wday)4 -0.0347485024 0.0174827874  -1.987584
   factor(wday)5 -0.0211209881 0.0174007206  -1.213800
   factor(wday)6 -0.0408367290 0.0175023441  -2.333215
   factor(wday)7 -0.0319908241 0.0174353192  -1.834829
 lo(temp05, 0.9) -4.7103520274 0.4099034675 -11.491369
       relhum01  0.0017452289 0.0006882433   2.535773
          smk04  0.0009344724 0.0001421451   6.574076
(Dispersion Parameter for Robust Poisson family taken to be 0.8483037 )
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5990.195 on 6042.0251494 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality

```
fanal2_gam(formula=allcard~lo(Date,.0274) + factor(wday)+ lo(temp05,.9)
+relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = allcard ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median        3Q     Max
 -2.922001 -0.7614346 -0.06585801 0.602171 2.72433
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.7738020330 0.0603275003  29.4028764
lo(Date, 0.0274) -3.4483747097 0.4082980379  -8.4457293
   factor(wday)2 -0.0196987151 0.0181662138  -1.0843600
   factor(wday)3 -0.0295587707 0.0182259354  -1.6217972
   factor(wday)4 -0.0403018351 0.0182757364  -2.2052099
   factor(wday)5 -0.0511554272 0.0183252725  -2.7915234
   factor(wday)6 -0.0806901243 0.0184532406  -4.3726804
   factor(wday)7 -0.0497309216 0.0183178416  -2.7148898
 lo(temp05, 0.9) -5.4413190830 0.4313731148 -12.6139504
        relhum01  0.0006058808 0.0007265436   0.8339222
           smk04  0.0005701843 0.0001536407   3.7111537
(Dispersion Parameter for Robust Poisson family taken to be 0.8689932 )
    Null Deviance: 7357.422 on 6118 degrees of freedom
Residual Deviance: 6121.034 on 6042.0559596 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 0-64

```
> fanal2_gam(formula=card064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = card064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.959468 -1.310056 -0.1141178 0.5837704 3.304884
Coefficients:
                         Value   Std. Error     t value
     (Intercept)   0.2965143664 0.1408294196   2.1054860
lo(Date, 0.0274) -15.8464052934 0.9461934155 -16.7475328
   factor(wday)2  -0.0397143610 0.0419573600  -0.9465410
   factor(wday)3  -0.0762625934 0.0423831976  -1.7993591
   factor(wday)4  -0.0742053276 0.0423416148  -1.7525389
   factor(wday)5  -0.0737499179 0.0423349087  -1.7420592
   factor(wday)6  -0.0678330019 0.0422565926  -1.6052644
   factor(wday)7  -0.1034791939 0.0426338664  -2.4271595
 lo(temp05, 0.9)  -6.0431685728 1.0107170949  -5.9790901
        relhum01  -0.0013599830 0.0017025668  -0.7987839
           smk04  -0.0002106668 0.0003741705  -0.5630236
(Dispersion Parameter for Robust Poisson family taken to be 0.908293 )
    Null Deviance: 7578.528 on 6118 degrees of freedom
Residual Deviance: 6988.511 on 6042.0533156 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 65-74

```
> fanal2_gam(formula=card6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = card6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -2.184419 -0.7201202 -0.2457742 0.5206571 2.878627
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  0.3321408233 0.1166292500  2.8478347
lo(Date, 0.0274) -6.3700942770 0.7855880628 -8.1086954
   factor(wday)2  0.0340315740 0.0348051229  0.9777749
   factor(wday)3 -0.0099382023 0.0351615257 -0.2826442
   factor(wday)4 -0.0268018834 0.0352685114 -0.7599380
   factor(wday)5 -0.0429398938 0.0354151954 -1.2124709
   factor(wday)6 -0.0711485657 0.0356497984 -1.9957635
   factor(wday)7 -0.0375367633 0.0353611357 -1.0615260
 lo(temp05, 0.9) -6.1480596491 0.8267693338 -7.4362454
       relhum01  0.0017058953 0.0014037241  1.2152640
          smk04  0.0009122832 0.0002833101  3.2200874
(Dispersion Parameter for Robust Poisson family taken to be 0.8619593 )
    Null Deviance: 7363.793 on 6118 degrees of freedom
Residual Deviance: 6831.446 on 6042.034752 degrees of freedom
```

all cardio/vascular mortality age 75+

```
> fanal2_gam(formula=card75~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,+ data=dubthesis,
family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = card75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -2.581144 -0.7888646 -0.07848423 0.5921397 3.184903
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.1581960891 0.0815769083  14.1975973
lo(Date, 0.0274)  1.6367354459 0.5592621404   2.9265980
   factor(wday)2 -0.0295683579 0.0247440407  -1.1949689
   factor(wday)3 -0.0143259021 0.0247220931  -0.5794777
   factor(wday)4 -0.0302853622 0.0248069788  -1.2208404
   factor(wday)5 -0.0426682261 0.0248739988  -1.7153746
   factor(wday)6 -0.0818751150 0.0251121439  -3.2603793
   factor(wday)7 -0.0346860121 0.0248231091  -1.3973275
 lo(temp05, 0.9) -4.7134684975 0.5864684409  -8.0370369
       relhum01  0.0006419243 0.0009824104   0.6534176
          smk04  0.0005406138 0.0002107169   2.5655925
(Dispersion Parameter for Robust Poisson family taken to be 0.8732492 )
    Null Deviance: 7249.318 on 6118 degrees of freedom
Residual Deviance: 6373.595 on 6042.0420525 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all respiratory mortality

```
> fanal2_gam(formula=allresp~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = allresp ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.455623 -0.8160331 -0.1951883 0.5594515 3.140087
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  0.219852720 0.1100311242  1.99809573
lo(Date, 0.0274) -3.684088414 0.7346618523 -5.01467226
   factor(wday)2 -0.045547165 0.0335043830 -1.35943901
   factor(wday)3 -0.060288558 0.0336422146 -1.79205083
   factor(wday)4 -0.018566328 0.0332230109 -0.55883943
   factor(wday)5 -0.039464648 0.0334629290 -1.17935427
   factor(wday)6 -0.001236856 0.0331535044 -0.03730696
   factor(wday)7 -0.049041553 0.0335351864 -1.46239095
 lo(temp05, 0.9) -7.518161614 0.7895501458 -9.52208248
        relhum01  0.005058403 0.0013201383  3.83172230
           smk04  0.001744115 0.0002304442  7.56849155
(Dispersion Parameter for Robust Poisson family taken to be 0.8928889 )
    Null Deviance: 8671.776 on 6118 degrees of freedom
Residual Deviance: 6919.25 on 6041.6196445 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 0-64

```
> fanal2_gam(formula=resp064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust( poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -1.565671 -0.6756737 -0.5812599 -0.4501095 3.112607
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  -1.981523807 0.3276795577 -6.04713892
lo(Date, 0.0274) -17.905875899 2.1105602070 -8.48394461
   factor(wday)2  -0.009125735 0.1007831270 -0.09054824
   factor(wday)3   0.084351342 0.0984460327  0.85682825
   factor(wday)4   0.057323230 0.0991070177  0.57839729
   factor(wday)5   0.087116591 0.0984337205  0.88502792
   factor(wday)6   0.006022662 0.1003104029  0.06004026
   factor(wday)7   0.056027281 0.0990843507  0.56545036
 lo(temp05, 0.9)  -2.718595155 2.3343360201 -1.16461175
        relhum01   0.004792095 0.0039161852  1.22366396
           smk04   0.001977716 0.0006640242  2.97837948
(Dispersion Parameter for Robust Poisson family taken to be 0.9330383 )
    Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4286.524 on 6041.4058757 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 65-74

```
> fanal2_gam(formula=resp6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -1.824545 -0.9140689 -0.7796628 0.6148059 3.323171
Coefficients:
                        Value   Std. Error    t value
     (Intercept) -0.902326105 0.2287143358 -3.9452101
lo(Date, 0.0274) -7.087598817 1.5364910221 -4.6128475
   factor(wday)2 -0.135778417 0.0696661116 -1.9489880
   factor(wday)3 -0.078200229 0.0686360510 -1.1393463
   factor(wday)4 -0.075123471 0.0685903158 -1.0952489
   factor(wday)5 -0.066388716 0.0683915309 -0.9707154
   factor(wday)6 -0.059653674 0.0682291913 -0.8743131
   factor(wday)7 -0.103512423 0.0690376611 -1.4993617
 lo(temp05, 0.9) -9.689217488 1.6549748953 -5.8546009
        relhum01  0.001999763 0.0027567993  0.7253929
           smk04  0.001062144 0.0004895811  2.1694960
(Dispersion Parameter for Robust Poisson family taken to be 0.9652209 )
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5733.969 on 6041.4717718 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

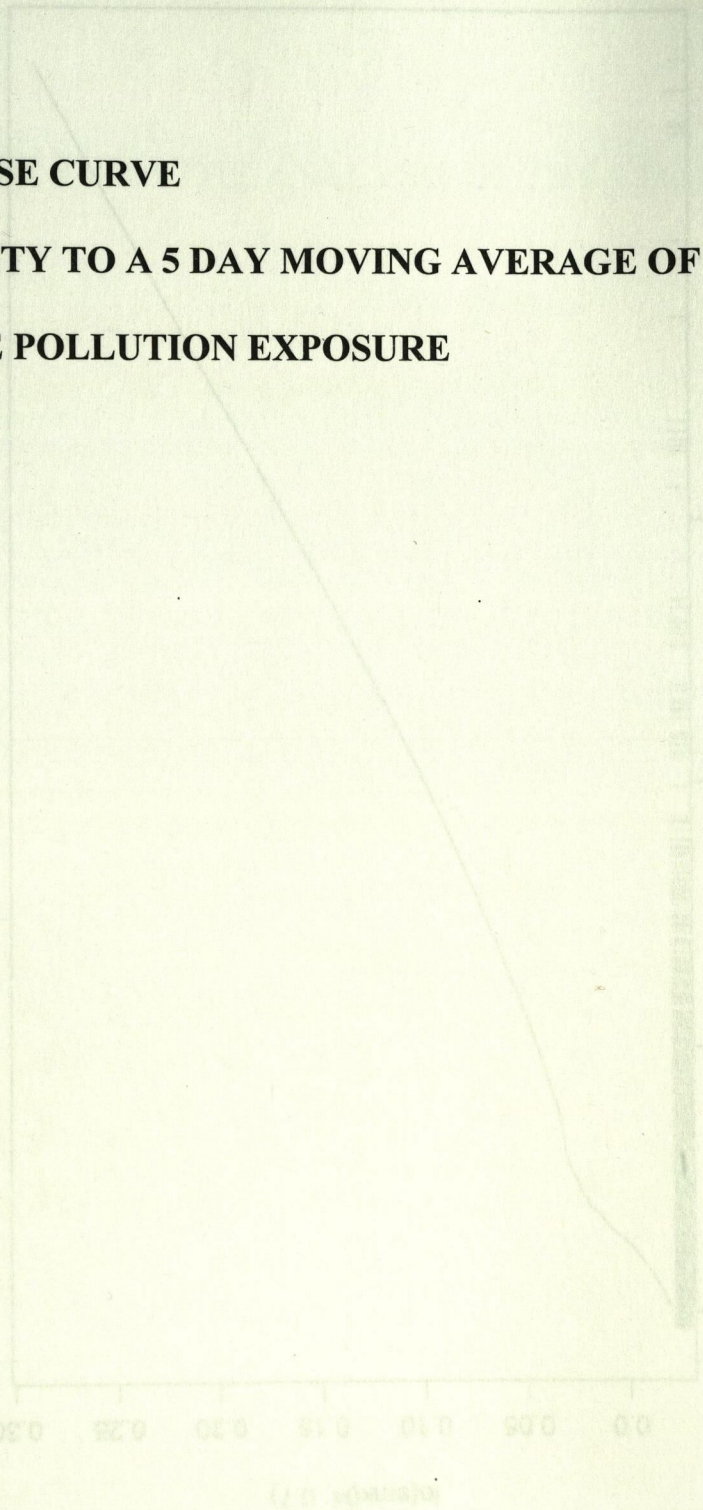
all respiratory mortality age 75+

```
> fanal2_gam(formula=resp75~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +smk04,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal2)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
      Min        1Q     Median        3Q       Max
 -2.182377 -1.264892 -0.1000091 0.5433732 3.237505
Coefficients:
                       Value   Std. Error    t value
     (Intercept) -0.319415870 0.1417588407 -2.2532342
lo(Date, 0.0274)  0.331908594 0.9574585370  0.3466558
   factor(wday)2 -0.017455541 0.0429909422 -0.4060283
   factor(wday)3 -0.078522967 0.0436060909 -1.8007339
   factor(wday)4 -0.007940698 0.0428821766 -0.1851748
   factor(wday)5 -0.062846199 0.0434684583 -1.4457886
   factor(wday)6  0.008544266 0.0427246322  0.1999845
   factor(wday)7 -0.051688864 0.0433178285 -1.1932469
 lo(temp05, 0.9) -7.561366202 1.0192877873 -7.4182839
        relhum01  0.005835942 0.0017006548  3.4315853
           smk04  0.001923480 0.0002934505  6.5547005
(Dispersion Parameter for Robust Poisson family taken to be 0.9414376 )
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 7010.183 on 6041.5997222 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

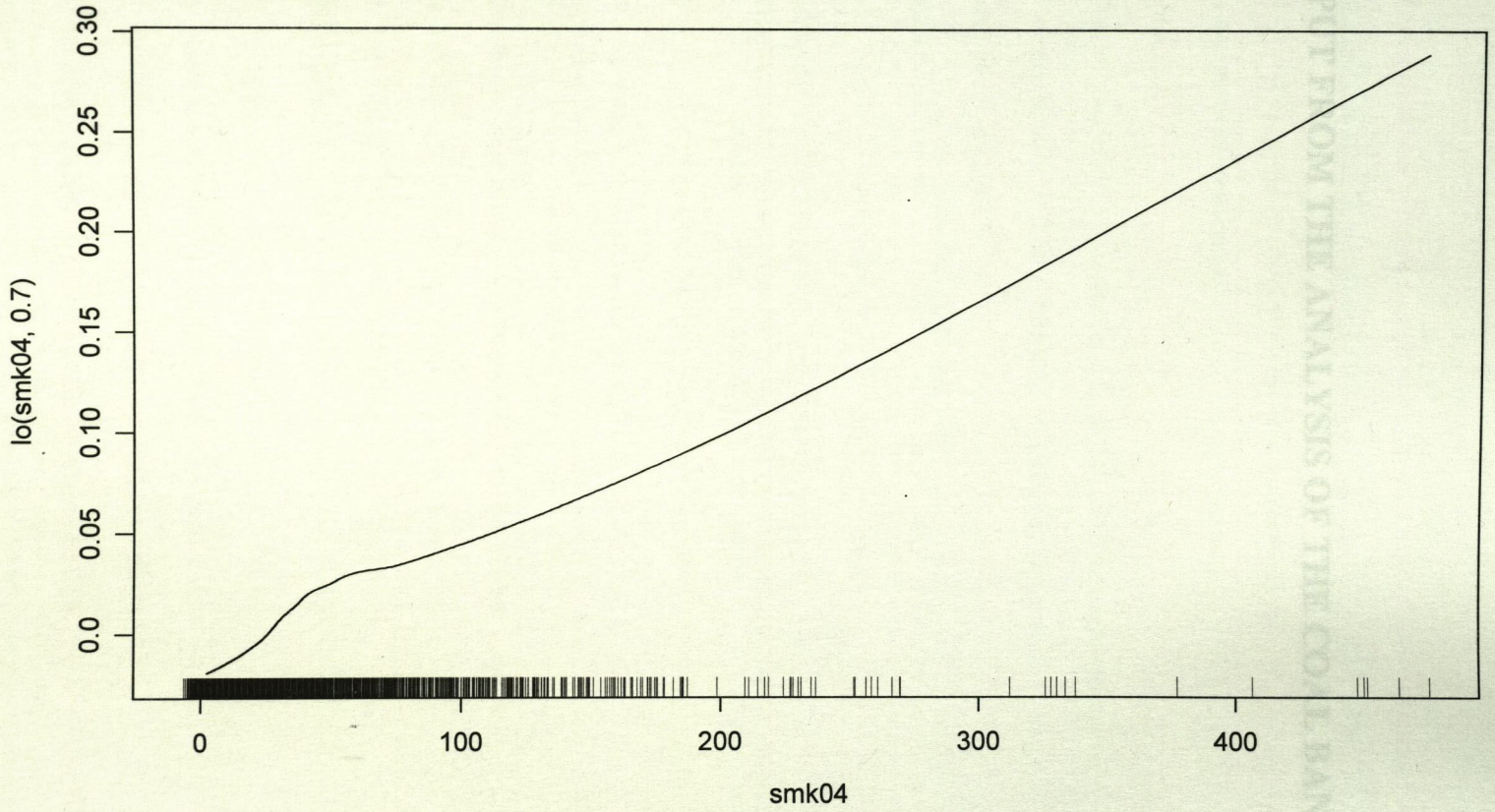
APPENDIX X

DOSE RESPONSE CURVE

ALL MORTALITY TO A 5 DAY MOVING AVERAGE OF PARTICULATE POLLUTION EXPOSURE



Dose response curve for all mortality to a five day moving average of particulate pollution



Appendix XI

MODEL OUTPUT FROM THE ANALYSIS OF THE COAL BAN

All mortality

```
> fanal3_gam(formula=allmort~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,+ data=dubthesis, family=
robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allmort ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -3.140936 -0.7423965 -0.06334189 0.6322934 2.994929
Coefficients:             Value   Std. Error     t value
     (Intercept)  2.451531526 0.0410723980  59.6880544
lo(Date, 0.0274) -0.730863124 0.4793384312  -1.5247330
   factor(wday)2 -0.010811016 0.0124892497  -0.8656257
   factor(wday)3 -0.013261763 0.0124899397  -1.0617956
   factor(wday)4 -0.019657545 0.0125247602  -1.5694948
   factor(wday)5 -0.008672678 0.0124904598  -0.6943442
   factor(wday)6 -0.016403191 0.0125088440  -1.3113274
   factor(wday)7 -0.032333731 0.0125539413  -2.5755840
 lo(temp05, 0.9) -5.186679366 0.2642916164 -19.6248350
        relhum01  0.001780358 0.0004928249   3.6125569
             ban -0.023046362 0.0127328597  -1.8099911
(Dispersion Parameter for Robust Poisson family taken to be 0.8666549
    Null Deviance: 7885.146 on 6118 degrees of freedom
Residual Deviance: 6008.908 on 6042.0788041 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 0-64

```
> fanal3_gam(formula=all064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.552394 -0.7362112 -0.06218548 0.5756831 3.311061
Coefficients:
                        Value  Std. Error     t value
     (Intercept)   1.022923869 0.085282170  11.9945807
lo(Date, 0.0274) -10.629952924 0.966885394 -10.9940154
   factor(wday)2  -0.009991817 0.025759978  -0.3878814
   factor(wday)3  -0.024999201 0.025855326  -0.9668879
   factor(wday)4  -0.015512803 0.025813312  -0.6009614
   factor(wday)5  -0.024694014 0.025875983  -0.9543218
   factor(wday)6   0.022374843 0.025570653   0.8750204
   factor(wday)7  -0.048476676 0.026050049  -1.8609054
 lo(temp05, 0.9)  -2.809131215 0.541132686  -5.1912059
        relhum01   0.001052950 0.001025604   1.0266637
             ban   0.040137389 0.026506728   1.5142340
(Dispersion Parameter for Robust Poisson family taken to be 0.8648385
    Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6339.145 on 6042.1170894 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 30-64

```
> fanal3_gam(formula=all3064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = all3064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.421115 -0.8363681 -0.1472813 0.5810849 3.269487
Coefficients:
                          Value  Std. Error       t value
     (Intercept)  1.020729e+000 0.088741041  11.502328232
lo(Date, 0.0274) -9.554785e+000 1.012501522  -9.436810290
   factor(wday)2  3.955298e-003 0.026795071   0.147612908
   factor(wday)3 -2.028088e-002 0.026931388  -0.753057230
   factor(wday)4 -1.003571e-002 0.026913138  -0.372892597
   factor(wday)5 -2.763043e-002 0.027019609  -1.022606452
   factor(wday)6  2.454218e-002 0.026681003   0.919837410
   factor(wday)7 -4.535573e-002 0.027144925  -1.670873311
 lo(temp05, 0.9) -3.295156e+000 0.563538543  -5.847259356
        relhum01 -5.643109e-006 0.001067446  -0.005286553
             ban  4.830669e-003 0.027673062   0.174562126
(Dispersion Parameter for Robust Poisson family taken to be 0.8470135)
    Null Deviance: 7309.934 on 6118 degrees of freedom
Residual Deviance: 6384.633 on 6042.1098418 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 65-74

```
> fanal3_gam(formula=all6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robu
st(    poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.625402 -0.7682761 -0.1041175 0.5870783 3.014646
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.130139861 0.0784107435  14.4130742
lo(Date, 0.0274) -4.470103180 0.9119683888  -4.9015988
   factor(wday)2  0.011393940 0.0236979050   0.4807995
   factor(wday)3  0.002890002 0.0237460674   0.1217044
   factor(wday)4 -0.020871579 0.0238698167  -0.8743921
   factor(wday)5  0.005565766 0.0237046902   0.2347960
   factor(wday)6 -0.025756742 0.0238685364  -1.0791085
   factor(wday)7 -0.038457433 0.0239736628  -1.6041534
 lo(temp05, 0.9) -6.368111186 0.5015003059 -12.6981202
        relhum01  0.001667221 0.0009411166   1.7715353
             ban  0.008685621 0.0243512764   0.3566803
(Dispersion Parameter for Robust Poisson family taken to be 0.8519789
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6136.002 on 6042.0534603 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 75+

```
> fanal3_gam(formula=all75~lo(Date,.0274) + factor(wday)+ lo(temp05,.9)
+relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.943175 -0.759965 -0.05956071 0.6208844 2.876554
Coefficients:
                       Value   Std. Error    t value
     (Intercept)  1.750991363 0.0572958235  30.560541
lo(Date, 0.0274)  5.935020996 0.6773376371   8.762278
   factor(wday)2 -0.035051574 0.0174847683  -2.004692
   factor(wday)3 -0.022476355 0.0174261235  -1.289808
   factor(wday)4 -0.034689447 0.0174899811  -1.983390
   factor(wday)5 -0.019572352 0.0174025308  -1.124684
   factor(wday)6 -0.038886174 0.0175054036  -2.221381
   factor(wday)7 -0.030983060 0.0174356818  -1.776992
 lo(temp05, 0.9) -5.880929083 0.3717358243 -15.820184
        relhum01  0.002246185 0.0006869431   3.269828
             ban -0.073239545 0.0176487475  -4.149844
(Dispersion Parameter for Robust Poisson family taken to be 0.8480313
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 6000.533 on 6042.0352435 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all mortality age 30+

```
 fanal3_gam(formula=allmort30~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allmort30 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robust(poisson), data =
dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -3.114792 -0.736019 -0.05217454 0.6287086 2.976131
Coefficients:
                      Value   Std. Error     t value
     (Intercept)  2.444268014 0.0414834323  58.9215471
lo(Date, 0.0274) -0.314812568 0.4853014362  -0.6486949
   factor(wday)2 -0.009892372 0.0126110138  -0.7844232
   factor(wday)3 -0.013344825 0.0126166693  -1.0577138
   factor(wday)4 -0.022993180 0.0126575305  -1.8165613
   factor(wday)5 -0.010444892 0.0126194041  -0.8276850
   factor(wday)6 -0.017268221 0.0126398379  -1.3661742
   factor(wday)7 -0.032817633 0.0126792476  -2.5882950
 lo(temp05, 0.9) -5.312358644 0.2669741989 -19.8983972
        relhum01  0.001648670 0.0004976633   3.3128221
             ban -0.031347055 0.0128693706  -2.4357878
(Dispersion Parameter for Robust Poisson family taken to be 0.8648895
    Null Deviance: 7892.433 on 6118 degrees of freedom
Residual Deviance: 6019.449 on 6042.0743784 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality

```
> fanal3_gam(formula=allcard~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allcard ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robu
st(   poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median     3Q    Max
 -2.930786 -0.7626136 -0.06330997 0.6076367 2.71152
Coefficients:
                        Value  Std. Error    t value
     (Intercept)  1.7784726254 0.060365595  29.461693
lo(Date, 0.0274) -2.8177006118 0.704478279  -3.999698
   factor(wday)2 -0.0201400893 0.018164792  -1.108743
   factor(wday)3 -0.0299846305 0.018226109  -1.645147
   factor(wday)4 -0.0408747647 0.018277548  -2.236337
   factor(wday)5 -0.0504703976 0.018322233  -2.754599
   factor(wday)6 -0.0797851667 0.018448860  -4.324667
   factor(wday)7 -0.0490818294 0.018314536  -2.679939
 lo(temp05, 0.9) -6.1493473247 0.387291681 -15.877819
        relhum01  0.0008934485 0.000725021   1.232307
             ban -0.0344144522 0.018881222  -1.822681
(Dispersion Parameter for Robust Poisson family taken to be 0.8685235
    Null Deviance: 7357.422 on 6118 degrees of freedom
Residual Deviance: 6123.299 on 6042.061081 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 0-64

```
> fanal3_gam(formula=card064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = card064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robu
st(   poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min        1Q    Median        3Q       Max
 -1.961078 -1.31025 -0.114231 0.5848199 3.303282
Coefficients:
                         Value  Std. Error    t value
     (Intercept)   0.314608910 0.140727564  2.2355884
lo(Date, 0.0274) -14.619811298 1.593896891 -9.1723695
   factor(wday)2  -0.039755914 0.041952494 -0.9476412
   factor(wday)3  -0.076139687 0.042376279 -1.7967526
   factor(wday)4  -0.074401478 0.042335091 -1.7574423
   factor(wday)5  -0.074217419 0.042324562 -1.7535307
   factor(wday)6  -0.068270435 0.042244425 -1.6160815
   factor(wday)7  -0.103743777 0.042627152 -2.4337487
 lo(temp05, 0.9)  -5.805188094 0.894275261 -6.4915003
        relhum01  -0.001483497 0.001698576 -0.8733770
             ban  -0.035909364 0.044241407 -0.8116687
(Dispersion Parameter for Robust Poisson family taken to be 0.9080321
    Null Deviance: 7578.528 on 6118 degrees of freedom
Residual Deviance: 6988.003 on 6042.0522419 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 30-64

```
> fanal3_gam(formula=card3064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = card3064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = rob
ust(  poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.961791 -1.308476 -0.1086253 0.5776227 3.322347
Coefficients:
                         Value  Std. Error    t value
     (Intercept)   0.325442673 0.141765478  2.2956412
lo(Date, 0.0274) -14.757855760 1.607275795 -9.1819063
   factor(wday)2  -0.041339354 0.042210706 -0.9793571
   factor(wday)3  -0.078564149 0.042649605 -1.8420839
   factor(wday)4  -0.076916851 0.042607150 -1.8052569
   factor(wday)5  -0.077418686 0.042605714 -1.8170963
   factor(wday)6  -0.072429981 0.042532644 -1.7029268
   factor(wday)7  -0.113336635 0.042974291 -2.6373125
 lo(temp05, 0.9)  -5.897394049 0.900280416 -6.5506191
        relhum01  -0.001744234 0.001711419 -1.0191745
             ban  -0.040640872 0.044582085 -0.9115965
(Dispersion Parameter for Robust Poisson family taken to be 0.9083932
    Null Deviance: 7569.478 on 6118 degrees of freedom
Residual Deviance: 6977.863 on 6042.054122 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 65-74

```
> fanal3_gam(formula=card6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = card6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = rob
ust(  poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.164007 -0.7230913 -0.2388408 0.527165 2.885318
Coefficients:
                      Value Std. Error    t value
     (Intercept)  0.319037604 0.11687475  2.7297394
lo(Date, 0.0274) -6.665370762 1.35875420 -4.9055015
   factor(wday)2  0.034342265 0.03485771  0.9852130
   factor(wday)3 -0.010171002 0.03522090 -0.2887774
   factor(wday)4 -0.026682389 0.03533072 -0.7552177
   factor(wday)5 -0.041298349 0.03547150 -1.1642684
   factor(wday)6 -0.069830226 0.03570717 -1.9556361
   factor(wday)7 -0.035902875 0.03541516 -1.0137713
 lo(temp05, 0.9) -7.309124924 0.74260856 -9.8425002
        relhum01  0.002220834 0.00140340  1.5824668
             ban -0.013975985 0.03649699 -0.3829353
 (Dispersion Parameter for Robust Poisson family taken to be 0.8649265
    Null Deviance: 7363.793 on 6118 degrees of freedom
Residual Deviance: 6839.992 on 6042.0428261 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 75+

```
> fanal3_gam(formula=card75~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = card75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robus
t(    poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q     Max
 -2.572038 -0.7957093 -0.07733357 0.5920086 3.17819
Coefficients:
                         Value  Std. Error     t value
     (Intercept)  1.1725624595 0.081588350  14.3716898
lo(Date, 0.0274)  3.3000960430 0.964976859   3.4198707
   factor(wday)2 -0.0298610932 0.024721896  -1.2078804
   factor(wday)3 -0.0143055575 0.024700121  -0.5791695
   factor(wday)4 -0.0308144858 0.024789522  -1.2430448
   factor(wday)5 -0.0417825416 0.024850124  -1.6813816
   factor(wday)6 -0.0810489848 0.025089175  -3.2304364
   factor(wday)7 -0.0343006384 0.024799767  -1.3831033
 lo(temp05, 0.9) -5.3879657648 0.528980222 -10.1855713
        relhum01  0.0009450501 0.000979191   0.9651335
             ban -0.0660877288 0.025459459  -2.5958025
(Dispersion Parameter for Robust Poisson family taken to be 0.8713515
    Null Deviance: 7249.318 on 6118 degrees of freedom
Residual Deviance: 6368.947 on 6042.0467259 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all cardio/vascular mortality age 30+

```
> fanal3_gam(formula=allcard30~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allcard30 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = ro
bust( poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.927932 -0.7628155 -0.06153793 0.6031293 2.715315
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.7796847994 0.0603663984  29.481381
lo(Date, 0.0274) -2.8011086978 0.7045630817  -3.975668
   factor(wday)2 -0.0200519315 0.0181595121  -1.104211
   factor(wday)3 -0.0299494914 0.0182204515  -1.643729
   factor(wday)4 -0.0410270596 0.0182731878  -2.245205
   factor(wday)5 -0.0508822580 0.0183204706  -2.777344
   factor(wday)6 -0.0804283343 0.0184497131  -4.359327
   factor(wday)7 -0.0500526950 0.0183203638  -2.732080
 lo(temp05, 0.9) -6.1619586649 0.3872518856 -15.912017
        relhum01  0.0008543634 0.0007250163   1.178406
             ban -0.0352986001 0.0188818313  -1.869448
(Dispersion Parameter for Robust Poisson family taken to be 0.8660874
Null Deviance: 7347.237 on 6118 degrees of freedom
Residual Deviance: 6111.22 on 6042.0611994 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all respiratory mortality

```
> fanal3_gam(formula=allresp~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allresp ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robu
st(   poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q     Max
 -2.490223 -0.8157606 -0.1952723 0.5627268 3.15954
Coefficients:
                        Value  Std. Error     t value
     (Intercept)   0.2392318813 0.110338973   2.16815396
lo(Date, 0.0274)   0.2739178086 1.272534277   0.21525378
   factor(wday)2  -0.0450376620 0.033590782  -1.34077446
   factor(wday)3  -0.0607244254 0.033737629  -1.79990200
   factor(wday)4  -0.0187700600 0.033337480  -0.56303176
   factor(wday)5  -0.0347974967 0.033543151  -1.03739498
   factor(wday)6   0.0009302397 0.033259870   0.02796883
   factor(wday)7  -0.0462563026 0.033615943  -1.37602277
 lo(temp05, 0.9) -10.0385762717 0.719041270 -13.96105715
        relhum01   0.0061793365 0.001322101   4.67387482
             ban  -0.1757472880 0.034623392  -5.07596969
(Dispersion Parameter for Robust Poisson family taken to be 0.8975342
    Null Deviance: 8671.776 on 6118 degrees of freedom
Residual Deviance: 6942.687 on 6041.6474995 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 0-64

```
> fanal3_gam(formula=resp064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robu
st(   poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.147822 -0.6774858 -0.5825549 -0.4483096 3.105406
Coefficients:
                        Value Std. Error     t value
     (Intercept)  -2.000635031 0.32767254 -6.10559264
lo(Date, 0.0274) -16.845623238 3.63461087 -4.63478040
   factor(wday)2  -0.008958455 0.10079116 -0.08888135
   factor(wday)3   0.085689274 0.09844458  0.87043164
   factor(wday)4   0.058844699 0.09912636  0.59363319
   factor(wday)5   0.092887366 0.09841202  0.94386195
   factor(wday)6   0.008171470 0.10040523  0.08138490
   factor(wday)7   0.059364608 0.09908751  0.59911292
 lo(temp05, 0.9)  -5.710885144 2.09125205 -2.73084498
        relhum01   0.006062038 0.00391773  1.54733426
             ban  -0.086795096 0.10475455 -0.82855679
(Dispersion Parameter for Robust Poisson family taken to be 0.9332661
    Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4290.071 on 6041.4314669 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 30-64

```
> fanal3_gam(formula=resp3064~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = resp3064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = rob
ust(  poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.141426 -0.6586795 -0.5704239 -0.4374874 3.101619
Coefficients:
                         Value  Std. Error    t value
     (Intercept)  -2.073837036 0.337757680 -6.1400145
lo(Date, 0.0274) -15.914558389 3.756229457 -4.2368440
   factor(wday)2   0.012808119 0.103346241  0.1239341
   factor(wday)3   0.062679968 0.102036135  0.6142919
   factor(wday)4   0.067341407 0.101966835  0.6604246
   factor(wday)5   0.072490450 0.101948601  0.7110490
   factor(wday)6   0.017665178 0.103279027  0.1710432
   factor(wday)7   0.052987677 0.102303795  0.5179444
 lo(temp05, 0.9)  -6.100991458 2.143333012 -2.8464972
        relhum01   0.006221387 0.004041964  1.5391989
             ban  -0.103363188 0.107835758 -0.9585242
(Dispersion Parameter for Robust Poisson family taken to be 0.9282292
    Null Deviance: 4536.43 on 6118 degrees of freedom
Residual Deviance: 4149.643 on 6041.4001756 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 64-75

```
> fanal3_gam(formula=resp6574~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = rob
ust   poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.648772 -0.9145415 -0.7794478 0.6110458 3.319649
Coefficients:
                        Value  Std. Error    t value
     (Intercept)  -0.888318272 0.228509915 -3.8874386
lo(Date, 0.0274)  -4.262310890 2.680647960 -1.5900301
   factor(wday)2  -0.136194211 0.069654261 -1.9552890
   factor(wday)3  -0.078167136 0.068624590 -1.1390543
   factor(wday)4  -0.076871487 0.068626391 -1.1201447
   factor(wday)5  -0.063919283 0.068363153 -0.9349961
   factor(wday)6  -0.056972940 0.068203330 -0.8353396
   factor(wday)7  -0.102569028 0.069027249 -1.4859208
 lo(temp05, 0.9) -11.266304817 1.493050273 -7.5458309
        relhum01   0.002723045 0.002745647  0.9917679
             ban  -0.120243093 0.073036138 -1.6463506
(Dispersion Parameter for Robust Poisson family taken to be 0.9650305
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5734.244 on 6041.4859056 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

all respiratory mortality age 75+

```
> fanal3_gam(formula=resp75~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = robus
t      poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.222192 -1.263012 -0.09961345 0.5314762 3.261903
Coefficients:
                        Value  Std. Error     t value
     (Intercept)  -0.291550073 0.142083810  -2.0519584
lo(Date, 0.0274)   5.343857720 1.644697275   3.2491437
   factor(wday)2  -0.017143711 0.043081908  -0.3979329
   factor(wday)3  -0.078231612 0.043706307  -1.7899387
   factor(wday)4  -0.005264659 0.042965135  -0.1225333
   factor(wday)5  -0.057301794 0.043547728  -1.3158389
   factor(wday)6   0.012425012 0.042836133   0.2900591
   factor(wday)7  -0.049053543 0.043413885  -1.1299045
 lo(temp05, 0.9) -10.496277339 0.930211245 -11.2837567
        relhum01   0.007099572 0.001702856   4.1692152
             ban  -0.216561881 0.044082651  -4.9126329
(Dispersion Parameter for Robust Poisson family taken to be 0.9461756
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 7032.979 on 6041.6241843 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

all respiratory mortality age 30+

```
> fanal3_gam(formula=allresp30~lo(Date,.0274) + factor(wday)+
lo(temp05,.9) +relhum01 +ban,
+ data=dubthesis, family=robust(poisson),na.action=na.omit)
> summary.glm(fanal3)
Call: gam(formula = allresp30 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban, family = ro
bust( poisson), data = dubthesis, na.action = na.omit)
Deviance Residuals:
       Min          1Q      Median          3Q       Max
 -2.491505 -0.8201152 -0.1914223 0.5640176 3.167539
Coefficients:
                        Value  Std. Error      t value
     (Intercept)   0.229275124 0.110784708   2.06955571
lo(Date, 0.0274)   0.471654741 1.278826365   0.36881844
   factor(wday)2  -0.043632081 0.033684621  -1.29531164
   factor(wday)3  -0.066805514 0.033896415  -1.97087255
   factor(wday)4  -0.019230996 0.033452105  -0.57488149
   factor(wday)5  -0.038470293 0.033688644  -1.14193652
   factor(wday)6   0.001021320 0.033366588   0.03060908
   factor(wday)7  -0.050288682 0.033765188  -1.48936480
 lo(temp05, 0.9) -10.097924989 0.721505375 -13.99563376
        relhum01   0.006239404 0.001327548   4.69994507
             ban  -0.178146520 0.034760429  -5.12498046
(Dispersion Parameter for Robust Poisson family taken to be 0.8977855
    Null Deviance: 8678.334 on 6118 degrees of freedom
Residual Deviance: 6951.7 on 6041.6454408 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

SENSSITIVITY ANALYSIS OF BAN

Notional introduction of ban in 1987

```
> bansen_gam(formula=allmort30~lo(Date,.0274) +factor(wday)+
lo(temp05,.9) + relhum01 +  ban87,+ data=fbanmd2,family=
robust(poisson),na.action=na.omit)
> summary.glm(bansen)
Call: gam(formula = allmort30 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban87, family = robust(poisson), data =
fbanmd2, na.action = na.omit)
Deviance Residuals:
     Min          1Q      Median          3Q       Max
 -3.11189 -0.7337148 -0.0497219 0.6313942 2.990599
Coefficients:          Value   Std. Error     t value
     (Intercept)  2.422975108 0.0441230528  54.9140405
lo(Date, 0.0274) -2.585125074 0.5369745049  -4.8142417
   factor(wday)2 -0.009938552 0.0126240090  -0.7872738
   factor(wday)3 -0.013425366 0.0126302310  -1.0629549
   factor(wday)4 -0.023014203 0.0126705270  -1.8163572
   factor(wday)5 -0.010549033 0.0126324511  -0.8350741
   factor(wday)6 -0.017209812 0.0126525191  -1.3601886
   factor(wday)7 -0.032663472 0.0126916613  -2.5736167
 lo(temp05, 0.9) -5.044339889 0.2681387890 -18.8124214
        relhum01  0.001499818 0.0005051295   2.9691762
           ban87  0.038841678 0.0136721702   2.8409299
(Dispersion Parameter for Robust Poisson family taken to be 0.8656361
    Null Deviance: 7892.433 on 6118 degrees of freedom
Residual Deviance: 6016.812 on 6042.0749651 degrees of freedom
```

Notional introduction of ban in 1993

```
> bansen_gam(formula=allmort30~lo(Date,.0274) +factor(wday)+
lo(temp05,.9) + relhum01 +  ban93,
+ data=fbanmd2, family=robust(poisson),na.action=na.omit)
> summary.glm(bansen)
Call: gam(formula = allmort30 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + ban93,
      family = robust(poisson), data = fbanmd2, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median        3Q       Max
 -3.114432 -0.7355083 -0.05391213 0.628773 2.976716
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  2.441189345 0.0430584672  56.6947573
lo(Date, 0.0274) -0.916748698 0.3704592739  -2.4746275
   factor(wday)2 -0.009866861 0.0126106874  -0.7824205
   factor(wday)3 -0.013351064 0.0126167075  -1.0582051
   factor(wday)4 -0.023011694 0.0126574301  -1.8180384
   factor(wday)5 -0.010470289 0.0126193335  -0.8297022
   factor(wday)6 -0.017292312 0.0126395279  -1.3681138
   factor(wday)7 -0.032791988 0.0126789807  -2.5863269
 lo(temp05, 0.9) -5.301099608 0.2678095791 -19.7942868
        relhum01  0.001585600 0.0005261974   3.0133170
           ban93 -0.017910877 0.0125492485  -1.4272470
(Dispersion Parameter for Robust Poisson family taken to be 0.8648538
    Null Deviance: 7892.433 on 6118 degrees of freedom
Residual Deviance: 6019.114 on 6042.0743328 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Appendix XII

MODEL OUTPUTS FOR MEDIUM TERM EXPOSURE EFFECT

0-64 AGE GROUP

lag 0-13

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk014,+ data = longterm,family = robust (poisson) ,na.action =
na.omit)  > summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk014,family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median        3Q       Max
 -2.55129 -0.736679 -0.06342755 0.577745 3.302666
Coefficients:           Value   Std. Error     t value
     (Intercept)  1.0414427066 0.0852327180  12.2188138
lo(Date, 0.0274) -9.1531317562 0.5750060128 -15.9183236
   factor(wday)2 -0.0099589640 0.0257631753  -0.3865581
   factor(wday)3 -0.0248566532 0.0258574905  -0.9612941
   factor(wday)4 -0.0154053898 0.0258153982  -0.5967520
   factor(wday)5 -0.0245855465 0.0258779341  -0.9500583
   factor(wday)6  0.0224118343 0.0255740778   0.8763497
   factor(wday)7 -0.0483347287 0.0260531434  -1.8552360
 lo(temp05, 0.9) -2.5255077402 0.6171962612  -4.0919038
        relhum01  0.0008923492 0.0010275507   0.8684235
          smk014  0.0003600138 0.0002701272   1.3327564
(Dispersion Parameter for Robust Poisson family taken to be 0.8651064
Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6340.262 on 6042.1153911 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-24

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk02
5,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.549131 -0.7381623 -0.06555235 0.5738746 3.307593
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  1.0450435096 0.0853870869  12.2388941
lo(Date, 0.0274) -9.0278925314 0.5858239272 -15.4105903
   factor(wday)2 -0.0121501928 0.0258371069  -0.4702614
   factor(wday)3 -0.0243196561 0.0259124976  -0.9385300
   factor(wday)4 -0.0189565005 0.0258928579  -0.7321131
   factor(wday)5 -0.0267609352 0.0259413804  -1.0315926
   factor(wday)6  0.0214286132 0.0256290279   0.8361071
   factor(wday)7 -0.0486201619 0.0261040700  -1.8625510
 lo(temp05, 0.9) -2.4453023871 0.6240539085  -3.9184153
        relhum01  0.0008311269 0.0010280755   0.8084298
          smk025  0.0004420828 0.0002974925   1.4860303
(Dispersion Parameter for Robust Poisson family taken to be 0.86538 )
    Null Deviance: 7226.356 on 6094 degrees of freedom
Residual Deviance: 6317.955 on 6018.3993962 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-29

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smklag030,
      family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.551731 -0.7364938 -0.06498625 0.576709 3.307913
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  1.0385785235 0.0852411819  12.1839996
lo(Date, 0.0274) -9.0954852191 0.5814367013 -15.6431219
   factor(wday)2 -0.0100026915 0.0257635750  -0.3882494
   factor(wday)3 -0.0249738920 0.0258581949  -0.9658018
   factor(wday)4 -0.0155211707 0.0258161220  -0.6012201
   factor(wday)5 -0.0247914998 0.0258792025  -0.9579700
   factor(wday)6  0.0225453456 0.0255732247   0.8815996
   factor(wday)7 -0.0482923859 0.0260533080  -1.8535990
 lo(temp05, 0.9) -2.5405042048 0.6242943289  -4.0694014
        relhum01  0.0008956549 0.0010255882   0.8733085
       smklag030  0.0004559451 0.0003047156   1.4962972
(Dispersion Parameter for Robust Poisson family taken to be 0.8650849
    Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6340.358 on 6042.1154391 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-34>

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk035,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk035,
      family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q     Max
 -2.558279 -0.7374866 -0.06283632 0.5751401 3.31253
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  1.0477649829 0.0854815635  12.2572042
lo(Date, 0.0274) -9.0244191295 0.5907431712 -15.2763833
   factor(wday)2 -0.0133428324 0.0258639673  -0.5158850
   factor(wday)3 -0.0250037656 0.0259372001  -0.9640117
   factor(wday)4 -0.0190947609 0.0259140239  -0.7368505
   factor(wday)5 -0.0271206779 0.0259734183  -1.0441705
   factor(wday)6  0.0215563883 0.0256575067   0.8401591
   factor(wday)7 -0.0475679035 0.0261223209  -1.8209677
 lo(temp05, 0.9) -2.4553083724 0.6294383253  -3.9007926
        relhum01  0.0007795629 0.0010265683   0.7593873
          smk035  0.0005137875 0.0003141149   1.6356673
(Dispersion Parameter for Robust Poisson family taken to be 0.8660373
    Null Deviance: 7215.993 on 6084 degrees of freedom
Residual Deviance: 6309.605 on 6008.5037345 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-39

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk040,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04
0,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min          1Q      Median          3Q       Max
 -2.563918 -0.7382595 -0.05897957 0.5730334 3.315281
Coefficients:
                          Value  Std. Error     t value
     (Intercept)  1.0485424315 0.085542663  12.2575379
lo(Date, 0.0274) -9.0059015544 0.592931084 -15.1887830
   factor(wday)2 -0.0129043564 0.025877551  -0.4986699
   factor(wday)3 -0.0249610688 0.025954285  -0.9617321
   factor(wday)4 -0.0185510180 0.025927834  -0.7154866
   factor(wday)5 -0.0270631207 0.025989681  -1.0413025
   factor(wday)6  0.0211703205 0.025666293   0.8248297
   factor(wday)7 -0.0479312032 0.026131364  -1.8342404
 lo(temp05, 0.9) -2.4578292112 0.632267981  -3.8873220
        relhum01  0.0007425876 0.001026007   0.7237648
          smk040  0.0006033768 0.000321193   1.8785494
(Dispersion Parameter for Robust Poisson family taken to be 0.8661321
    Null Deviance: 7215.182 on 6079 degrees of freedom
Residual Deviance: 6307.178 on 6003.5582965 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-44

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk045,
      family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.558588 -0.7390607 -0.0626525 0.576845 3.311318
Coefficients:
                         Value  Std. Error     t value
     (Intercept)  1.0352211811 0.085359583  12.1277676
lo(Date, 0.0274) -8.9720411557 0.585538849 -15.3227086
   factor(wday)2 -0.0098874807 0.025764024  -0.3837708
   factor(wday)3 -0.0248673558 0.025858066  -0.9616866
   factor(wday)4 -0.0153695952 0.025816142  -0.5953483
   factor(wday)5 -0.0247906377 0.025880035  -0.9579059
   factor(wday)6  0.0226385870 0.025573259   0.8852445
   factor(wday)7 -0.0482447684 0.026053547  -1.8517543
 lo(temp05, 0.9) -2.4499613410 0.631737633  -3.8781311
        relhum01  0.0008726592 0.001023449   0.8526650
          smk045  0.0006459859 0.000325851   1.9824580
(Dispersion Parameter for Robust Poisson family taken to be 0.8651271
    Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6340.585 on 6042.1152123 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-49

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk050,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk050,
    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q      Median        3Q       Max
 -2.557795 -0.7361417 -0.06212371 0.5728235 3.311156
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.0554289176 0.0859449288  12.2802931
lo(Date, 0.0274) -8.9430387589 0.5972144428 -14.9745855
   factor(wday)2 -0.0133782641 0.0258935159  -0.5166646
   factor(wday)3 -0.0245573352 0.0259637006  -0.9458334
   factor(wday)4 -0.0198886594 0.0259499144  -0.7664249
   factor(wday)5 -0.0262439524 0.0259968853  -1.0095037
   factor(wday)6  0.0204682864 0.0256944035   0.7966048
   factor(wday)7 -0.0484856073 0.0261590483  -1.8534928
 lo(temp05, 0.9) -2.3792519815 0.6372727177  -3.7334910
        relhum01  0.0006380112 0.0010284163   0.6203822
          smk050  0.0006713111 0.0003348715   2.0046826
(Dispersion Parameter for Robust Poisson family taken to be 0.8652175
Null Deviance: 7204.059 on 6069 degrees of freedom
Residual Deviance: 6294.275 on 5993.6757163 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-54

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk055, + data=longterm, family=robust
(poisson),na.action=na.omit)>
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk055,          > summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk05
5, family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -2.564629 -0.7345664 -0.06246716 0.5742603 3.313207
Coefficients:
                          Value   Std. Error     t value
      (Intercept)  1.0492167880 0.0860789103  12.1890110
lo(Date, 0.0274) -8.8587552930 0.5999074731 -14.7668694
   factor(wday)2 -0.0138314590 0.0259146379  -0.5337315
   factor(wday)3 -0.0234465457 0.0259734168  -0.9027132
   factor(wday)4 -0.0204106537 0.0259711796  -0.7858963
   factor(wday)5 -0.0272448972 0.0260218599  -1.0470004
   factor(wday)6  0.0199050771 0.0257149457   0.7740665
   factor(wday)7 -0.0484682396 0.0261664070  -1.8523078
 lo(temp05, 0.9) -2.3283027415 0.6395213529  -3.6406959
        relhum01  0.0006877868 0.0010287473   0.6685673
         smk055  0.0007495500 0.0003415143   2.1947835
(Dispersion Parameter for Robust Poisson family taken to be 0.8659132
    Null Deviance: 7196.788 on 6064 degrees of freedom
Residual Deviance: 6291.156 on 5988.7316762 degrees of freedom
```

Lag 0-59

```
longall_gam(formula=all064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk060,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk06
0,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median       3Q      Max
 -2.556935 -0.7365249 -0.06446534 0.578041 3.312662
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  1.0325423755 0.0856263673  12.0586965
lo(Date, 0.0274) -8.9282758565 0.5892652101 -15.1515408
   factor(wday)2 -0.0098875434 0.0257678443  -0.3837164
   factor(wday)3 -0.0248409747 0.0258623453  -0.9605074
   factor(wday)4 -0.0154011136 0.0258206067  -0.5964660
   factor(wday)5 -0.0246835717 0.0258834802  -0.9536419
   factor(wday)6  0.0225321565 0.0255780190   0.8809187
   factor(wday)7 -0.0482259257 0.0260571395  -1.8507759
 lo(temp05, 0.9) -2.4127268238 0.6382522037  -3.7802092
        relhum01  0.0008819824 0.0010225888   0.8624996
          smk060  0.0007168272 0.0003454644   2.0749672
(Dispersion Parameter for Robust Poisson family taken to be 0.8654849
Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6342.021 on 6042.1155162 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-89

```
lninty_gam(formula=all064~lo(Date,.0274)+
factor(wday)+lo(temp05,.9)+relhum01+smk090,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lninty)
Call: gam(formula = all064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk09
0,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.554569 -0.7377216 -0.06366378 0.5787568 3.307106
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.0132805823 0.0867550384  11.6797894
lo(Date, 0.0274) -8.5501710469 0.5958951678 -14.3484484
   factor(wday)2 -0.0099809228 0.0257574106  -0.3874971
   factor(wday)3 -0.0247849074 0.0258512209  -0.9587519
   factor(wday)4 -0.0154531046 0.0258105635  -0.5987124
   factor(wday)5 -0.0244971618 0.0258710025  -0.9468965
   factor(wday)6  0.0226089172 0.0255670095   0.8843004
   factor(wday)7 -0.0482172890 0.0260458566  -1.8512460
 lo(temp05, 0.9) -2.1251650511 0.6394554006  -3.3233984
        relhum01  0.0009239867 0.0010246539   0.9017550
          smk090  0.0012981265 0.0003796416   3.4193471
(Dispersion Parameter for Robust Poisson family taken to be 0.8646382
    Null Deviance: 7263.086 on 6118 degrees of freedom
Residual Deviance: 6338.604 on 6042.114751 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

ALL MORTALITY AGE 65-74

Lag 0-13

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk014,+
data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk014, family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q         Max
 -2.671714 -0.7643151 -0.1023724 0.5880647 2.999871
Coefficients:          Value   Std. Error     t value
     (Intercept)  1.140437467 0.0782176827  14.5803024
lo(Date, 0.0274) -2.977895207 0.5381358155  -5.5337242
   factor(wday)2  0.010117514 0.0236714039   0.4274150
   factor(wday)3  0.002702803 0.0237112158   0.1139884
   factor(wday)4 -0.022116995 0.0238395008  -0.9277457
   factor(wday)5  0.004776708 0.0236710640   0.2017952
   factor(wday)6 -0.026458897 0.0238373658  -1.1099757
   factor(wday)7 -0.039574406 0.0239453250  -1.6526986
 lo(temp05, 0.9) -5.029583918 0.5665426755  -8.8776788
        relhum01  0.001054890 0.0009423834   1.1193854
          smk014  0.001588666 0.0002364201   6.7196734
(Dispersion Parameter for Robust Poisson family taken to be 0.8503274
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6123.37 on 6042.0401397 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-24

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
25family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -2.669131 -0.7636442 -0.1013441  0.5840876  3.001269
Coefficients:
                        Value   Std. Error      t value
     (Intercept)  1.124877401 0.0782655486  14.37257414
lo(Date, 0.0274) -2.506383152 0.5481139269  -4.57274123
   factor(wday)2  0.011369345 0.0236899537   0.47992265
   factor(wday)3  0.002124377 0.0237452775   0.08946525
   factor(wday)4 -0.023072002 0.0238718404  -0.96649447
   factor(wday)5  0.002575281 0.0237056125   0.10863592
   factor(wday)6 -0.027411065 0.0238587041  -1.14889161
   factor(wday)7 -0.040781925 0.0239726489  -1.70118558
 lo(temp05, 0.9) -4.950564262 0.5718763295  -8.65670427
        relhum01  0.001035086 0.0009420474   1.09876202
          smk025  0.002217999 0.0002631224   8.42953248
(Dispersion Parameter for Robust Poisson family taken to be 0.8490879
    Null Deviance: 7008.862 on 6094 degrees of freedom
Residual Deviance: 6087.152 on 6018.3146498 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-29

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smkl
ag030 family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.654284 -0.7649057 -0.1015606 0.5848667 2.992286
Coefficients:
                        Value   Std. Error      t value
     (Intercept)  1.1298176185 0.0781927871  14.44912837
lo(Date, 0.0274) -2.4101713014 0.5451578033  -4.42105256
   factor(wday)2  0.0097690660 0.0236561208   0.41296145
   factor(wday)3  0.0016724453 0.0236980265   0.07057319
   factor(wday)4 -0.0228723053 0.0238215909  -0.96015020
   factor(wday)5  0.0044234292 0.0236563926   0.18698663
   factor(wday)6 -0.0274812510 0.0238227332  -1.15357254
   factor(wday)7 -0.0390568804 0.0239258401  -1.63241416
 lo(temp05, 0.9) -4.8953430695 0.5725373598  -8.55025962
        relhum01  0.0009252309 0.0009405909   0.98366986
       smklag030  0.0023563084 0.0002703258   8.71655101
(Dispersion Parameter for Robust Poisson family taken to be 0.8490333
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6118.095 on 6042.0368488 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-34

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk035,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
35,    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.635005 -0.7637244 -0.1008488 0.5832525 2.993125
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  1.111722320 0.0783340928  14.1920622
lo(Date, 0.0274) -2.295190231 0.5535524948  -4.1462919
   factor(wday)2  0.013212193 0.0237025267   0.5574171
   factor(wday)3  0.003099017 0.0237604443   0.1304276
   factor(wday)4 -0.020731349 0.0238843994  -0.8679870
   factor(wday)5  0.003464032 0.0237350217   0.1459460
   factor(wday)6 -0.025691103 0.0238845468  -1.0756370
   factor(wday)7 -0.040422461 0.0240031974  -1.6840449
 lo(temp05, 0.9) -4.981582651 0.5763677527  -8.6430627
        relhum01  0.001095626 0.0009404389   1.1650156
          smk035  0.002448765 0.0002792551   8.7689173
(Dispersion Parameter for Robust Poisson family taken to be 0.8484133
    Null Deviance: 6999.729 on 6084 degrees of freedom
Residual Deviance: 6077.156 on 6008.4292264 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-39

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk040,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
40,   family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.615798 -0.7647615 -0.1002173 0.5843864 2.995092
Coefficients:
                       Value   Std. Error     t value
     (Intercept)  1.110367097 0.0783539603  14.1711675
lo(Date, 0.0274) -2.220272661 0.5557375867  -3.9951817
   factor(wday)2  0.012862931 0.0237056463   0.5426104
   factor(wday)3  0.002933805 0.0237625263   0.1234635
   factor(wday)4 -0.022483643 0.0238943371  -0.9409612
   factor(wday)5  0.003078918 0.0237356362   0.1297171
   factor(wday)6 -0.026559501 0.0238785829  -1.1122729
   factor(wday)7 -0.040916128 0.0239965093  -1.7050867
 lo(temp05, 0.9) -4.977218202 0.5783660217  -8.6056546
        relhum01  0.001084945 0.0009395025   1.1548084
          smk040  0.002547184 0.0002859762   8.9069788
(Dispersion Parameter for Robust Poisson family taken to be 0.8474972
    Null Deviance: 6994.552 on 6079 degrees of freedom
Residual Deviance: 6070.142 on 6003.4893273 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-44

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk045,
    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -2.612788 -0.7680734 -0.1007453 0.5850259 2.994794
Coefficients:
                        Value   Std. Error      t value
     (Intercept)  1.1165399951 0.0782773715  14.26389227
lo(Date, 0.0274) -2.2009139350 0.5492862721  -4.00686135
   factor(wday)2  0.0102520671 0.0236552290   0.43339538
   factor(wday)3  0.0022511862 0.0236961654   0.09500213
   factor(wday)4 -0.0222736511 0.0238210210  -0.93504183
   factor(wday)5  0.0041180802 0.0236576894   0.17406942
   factor(wday)6 -0.0272146683 0.0238227426  -1.14238183
   factor(wday)7 -0.0387712915 0.0239229181  -1.62067568
 lo(temp05, 0.9) -4.8709206129 0.5787623859  -8.41609740
        relhum01  0.0009782954 0.0009382868   1.04264009
          smk045  0.0026587534 0.0002911028   9.13338260
(Dispersion Parameter for Robust Poisson family taken to be 0.8486042
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6116.917 on 6042.0384964 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-49

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk050,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
50,    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.618108 -0.7631002 -0.1019632 0.587293 3.00761
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.106960315 0.0788351475  14.0414568
lo(Date, 0.0274) -2.190892920 0.5610323322  -3.9051099
   factor(wday)2  0.012926796 0.0237674832   0.5438858
   factor(wday)3  0.003261732 0.0238252674   0.1369022
   factor(wday)4 -0.023115846 0.0239637797  -0.9646160
   factor(wday)5  0.003671477 0.0237983913   0.1542742
   factor(wday)6 -0.026317394 0.0239536024  -1.0986821
   factor(wday)7 -0.039691942 0.0240596370  -1.6497315
 lo(temp05, 0.9) -5.020535377 0.5839064743  -8.5981841
        relhum01  0.001115990 0.0009429128   1.1835564
          smk050  0.002556702 0.0003005146   8.5077459
(Dispersion Parameter for Robust Poisson family taken to be 0.8504369
    Null Deviance: 6984.544 on 6069 degrees of freedom
Residual Deviance: 6070.931 on 5993.6115771 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-54

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk055,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
55,    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -2.622286 -0.7635639 -0.1016019 0.5866814 3.009613
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.102206690 0.0789357862  13.9633333
lo(Date, 0.0274) -2.193524234 0.5632666204  -3.8942912
   factor(wday)2  0.014453474 0.0237711058   0.6080270
   factor(wday)3  0.003827404 0.0238355474   0.1605754
   factor(wday)4 -0.024047640 0.0239810559  -1.0027765
   factor(wday)5  0.003882387 0.0238097757   0.1630585
   factor(wday)6 -0.026092844 0.0239639198  -1.0888387
   factor(wday)7 -0.039861355 0.0240644445  -1.6564419
 lo(temp05, 0.9) -5.034099195 0.5859678899  -8.5910837
        relhum01  0.001170168 0.0009429297   1.2409919
          smk055  0.002560439 0.0003075394   8.3255638.
(Dispersion Parameter for Robust Poisson family taken to be 0.8507109
    Null Deviance: 6977.621 on 6064 degrees of freedom
Residual Deviance: 6066.872 on 5988.6710936 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-59

```
longall_gam(formula=all6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk060,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(longall)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
60,    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.615486 -0.76235 -0.1015944 0.5863003 2.998439
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  1.106690611 0.0785568770  14.0877623
lo(Date, 0.0274) -2.239764489 0.5530688455  -4.0497029
   factor(wday)2  0.011097662 0.0236652102   0.4689442
   factor(wday)3  0.002780442 0.0237116819   0.1172604
   factor(wday)4 -0.021761628 0.0238357801  -0.9129816
   factor(wday)5  0.004763978 0.0236715559   0.2012533
   factor(wday)6 -0.026749284 0.0238369901  -1.1221754
   factor(wday)7 -0.038515974 0.0239370183  -1.6090548
 lo(temp05, 0.9) -4.932740213 0.5849517413  -8.4327302
        relhum01  0.001097551 0.0009378129   1.1703303
          smk060  0.002646433 0.0003114146   8.4981000.
(Dispersion Parameter for Robust Poisson family taken to be 0.8492868
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6121.418 on 6042.0421907 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-89

```
> lninty_gam(formula=all6574~lo(Date,.0274)+
factor(wday)+lo(temp05,.9)+relhum01+smk090,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lninty)
Call: gam(formula = all6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
90,    family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.608447 -0.7598552 -0.1010182 0.5858056 3.004949
Coefficients:
                      Value   Std. Error     t value
     (Intercept)  1.073377687 0.0796217243  13.4809651
lo(Date, 0.0274) -2.115451141 0.5596767090  -3.7797734
   factor(wday)2  0.011139219 0.0236655224   0.4706940
   factor(wday)3  0.003145713 0.0237078230   0.1326867
   factor(wday)4 -0.020971693 0.0238342770  -0.8798963
   factor(wday)5  0.005116874 0.0236733110   0.2161453
   factor(wday)6 -0.026314392 0.0238375125  -1.1039068
   factor(wday)7 -0.038657857 0.0239390772  -1.6148432
 lo(temp05, 0.9) -4.899812375 0.5875242497  -8.3397619
        relhum01  0.001420760 0.0009399447   1.5115356
          smk090  0.002895955 0.0003462458   8.3638712.
(Dispersion Parameter for Robust Poisson family taken to be 0.8493954
    Null Deviance: 7044.158 on 6118 degrees of freedom
Residual Deviance: 6121.514 on 6042.0446925 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

ALL MORTALITY AGE 75+

Lag 0-13

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk014,+ data=longterm ,family =robust (poisson) , na.action
=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk014, family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median          3Q      Max
 -2.92958 -0.7644145 -0.05315284 0.6238984 2.857603
Coefficients:             Value   Std. Error    t value
     (Intercept)  1.733419287 0.0571617130  30.324831
lo(Date, 0.0274)  4.944992740 0.4020795550  12.298543
   factor(wday)2 -0.034835447 0.0174662188  -1.994447
   factor(wday)3 -0.022708651 0.0174109406  -1.304275
   factor(wday)4 -0.034894330 0.0174698163  -1.997407
   factor(wday)5 -0.020145901 0.0173895186  -1.158508
   factor(wday)6 -0.039552114 0.0174931581  -2.261005
   factor(wday)7 -0.031458393 0.0174205926  -1.805816
 lo(temp05, 0.9) -4.492765004 0.4146420263 -10.835286
        relhum01  0.001570220 0.0006877877   2.283001
          smk014  0.001641451 0.0001738716   9.440594
(Dispersion Parameter for Robust Poisson family taken to be 0.8470636
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5984.447 on 6042.0217945 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-24

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk025
family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.923275 -0.7594885 -0.05635319 0.6218191 2.84744
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.731444176 0.0571840891  30.278425
lo(Date, 0.0274)  6.088745742 0.4106201595  14.828171
   factor(wday)2 -0.034740935 0.0174797638  -1.987495
   factor(wday)3 -0.023961278 0.0174290911  -1.374786
   factor(wday)4 -0.036955779 0.0174879766  -2.113211
   factor(wday)5 -0.020563047 0.0173934958  -1.182226
   factor(wday)6 -0.040227656 0.0174977209  -2.299023
   factor(wday)7 -0.032712243 0.0174313751  -1.876630
 lo(temp05, 0.9) -3.940146054 0.4182475505  -9.420608
        relhum01  0.001173310 0.0006875413   1.706530
          smk025  0.002842223 0.0001920178  14.801874
(Dispersion Parameter for Robust Poisson family taken to be 0.8457263
    Null Deviance: 7570.343 on 6094 degrees of freedom
Residual Deviance: 5943.066 on 6018.2942249 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-29

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smklag
030,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.916146 -0.760952 -0.0554434 0.622047 2.84045
Coefficients:
                          Value   Std. Error    t value
     (Intercept)  1.726153211 0.0569851043  30.291306
lo(Date, 0.0274)  6.155253074 0.4068681350  15.128373
   factor(wday)2 -0.035674428 0.0173974481  -2.050555
   factor(wday)3 -0.024324167 0.0173439879  -1.402455
   factor(wday)4 -0.036997871 0.0174058485  -2.125600
   factor(wday)5 -0.021497763 0.0173221409  -1.241057
   factor(wday)6 -0.040622007 0.0174230674  -2.331507
   factor(wday)7 -0.032034884 0.0173549160  -1.845868
 lo(temp05, 0.9) -3.882183380 0.4178772749  -9.290248
        relhum01  0.001156006 0.0006847318   1.688261
     smklag030  0.003137820 0.0001968484  15.940288
(Dispersion Parameter for Robust Poisson family taken to be 0.8413332
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5949.125 on 6042.0111654 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-34

```
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk035
,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -2.92044 -0.7584068 -0.05549606 0.6185515 2.841358

Coefficients:
                        Value   Std. Error    t value
      (Intercept)  1.715673226 0.0571487642  30.021178
lo(Date, 0.0274)   6.576280012 0.4141746581  15.878036
   factor(wday)2  -0.034909113 0.0174583566  -1.999565
   factor(wday)3  -0.023377204 0.0174013086  -1.343416
   factor(wday)4  -0.036866411 0.0174726500  -2.109950
   factor(wday)5  -0.020621574 0.0173817547  -1.186392
   factor(wday)6  -0.037867902 0.0174768009  -2.166752
   factor(wday)7  -0.031748145 0.0174129647  -1.823248
 lo(temp05, 0.9) -3.737972815 0.4209524120  -8.879799
        relhum01  0.001149556 0.0006854571   1.677065
          smk035  0.003451173 0.0002035748  16.952848

(Dispersion Parameter for Robust Poisson family taken to be 0.8430711
    Null Deviance: 7559.213 on 6084 degrees of freedom
Residual Deviance: 5921.976 on 6008.3988262 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-39

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk040,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk040
,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q       Max
 -2.920289 -0.7551353 -0.05161474 0.6152387 2.839078
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.708528295 0.0571428611  29.899243
lo(Date, 0.0274)  6.708459343 0.4158386250  16.132362
   factor(wday)2 -0.035632264 0.0174557187  -2.041295
   factor(wday)3 -0.023963335 0.0173982491  -1.377342
   factor(wday)4 -0.036127811 0.0174665801  -2.068396
   factor(wday)5 -0.020705787 0.0173736443  -1.191793
   factor(wday)6 -0.038385915 0.0174635293  -2.198062
   factor(wday)7 -0.032162006 0.0174017397  -1.848206
 lo(temp05, 0.9) -3.697443239 0.4222597188  -8.756325
        relhum01  0.001180897 0.0006845167   1.725154
          smk040  0.003619734 0.0002088866  17.328705
(Dispersion Parameter for Robust Poisson family taken to be 0.8412683
    Null Deviance: 7552.86 on 6079 degrees of freedom
Residual Deviance: 5911.633 on 6003.4576476 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-44>

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk045
,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q       Max
 -2.916358 -0.7580909 -0.04902609 0.6181359 2.836264
Coefficients:
                         Value   Std. Error    t value
     (Intercept)  1.704491229 0.0570024765  29.902056
lo(Date, 0.0274)  6.549185822 0.4099433685  15.975831
   factor(wday)2 -0.034541653 0.0173797317  -1.987468
   factor(wday)3 -0.022522457 0.0173185422  -1.300482
   factor(wday)4 -0.035001744 0.0173879787  -2.012985
   factor(wday)5 -0.020772493 0.0173033013  -1.200493
   factor(wday)6 -0.038762949 0.0174003197  -2.227715
   factor(wday)7 -0.031288086 0.0173346681  -1.804943
 lo(temp05, 0.9) -3.746754709 0.4218235848  -8.882279
        relhum01  0.001219363 0.0006825246   1.786548
          smk045  0.003686143 0.0002124560  17.350144
(Dispersion Parameter for Robust Poisson family taken to be 0.8388203
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5941.678 on 6042.0122266 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-49

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk050,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk050
,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.913451 -0.7548116 -0.04771028 0.6178702 2.832612
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.704617814 0.0572807383  29.759006
lo(Date, 0.0274)  6.836765229 0.4187982905  16.324721
   factor(wday)2 -0.035204562 0.0174533009  -2.017072
   factor(wday)3 -0.022656737 0.0173907690  -1.302803
   factor(wday)4 -0.036151372 0.0174664483  -2.069761
   factor(wday)5 -0.018950196 0.0173655277  -1.091254
   factor(wday)6 -0.036243107 0.0174615759  -2.075592
   factor(wday)7 -0.031913863 0.0174078038  -1.833308
 lo(temp05, 0.9) -3.678879520 0.4249587082  -8.657028
        relhum01  0.001157361 0.0006844540   1.690926
          smk050  0.003797795 0.0002191199  17.332038
(Dispersion Parameter for Robust Poisson family taken to be 0.838711
    Null Deviance: 7535.93 on 6069 degrees of freedom
Residual Deviance: 5893.03 on 5993.5833479 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-54

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk055,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk055
,     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median        3Q       Max
 -2.921995 -0.7590728 -0.04999634 0.618207 2.842991
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.700939676 0.0574760956  29.593863
lo(Date, 0.0274)  6.794302083 0.4215449411  16.117622
   factor(wday)2 -0.035049315 0.0174978812  -2.003061
   factor(wday)3 -0.022183129 0.0174349077  -1.272340
   factor(wday)4 -0.036653545 0.0175148552  -2.092712
   factor(wday)5 -0.018540725 0.0174085156  -1.065038
   factor(wday)6 -0.036492071 0.0175049732  -2.084669
   factor(wday)7 -0.032438890 0.0174472904  -1.859251
 lo(temp05, 0.9) -3.742427450 0.4273914580  -8.756440
        relhum01  0.001216207 0.0006859185   1.773107
          smk055  0.003758795 0.0002250597  16.701321
(Dispersion Parameter for Robust Poisson family taken to be 0.8431977
    Null Deviance: 7533.62 on 6064 degrees of freedom
Residual Deviance: 5908.225 on 5988.6465541 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-59>

```
flong_gam(formula=all75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+relhu
m01+smk060,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(flong)
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk060
,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -2.924334 -0.7587071 -0.05279223 0.6179507 2.845188
Coefficients:
                      Value   Std. Error    t value
    (Intercept)  1.688538616 0.0573347375  29.450534
lo(Date, 0.0274)  6.496506843 0.4140136172  15.691529
   factor(wday)2 -0.034059806 0.0174252784  -1.954620
   factor(wday)3 -0.021956005 0.0173669856  -1.264238
   factor(wday)4 -0.034627037 0.0174377269  -1.985754
   factor(wday)5 -0.020028974 0.0173502771  -1.154389
   factor(wday)6 -0.038388348 0.0174469687  -2.200288
   factor(wday)7 -0.030911956 0.0173806511  -1.778527
 lo(temp05, 0.9) -3.822429395 0.4273937050  -8.943579
        relhum01  0.001409090 0.0006836214   2.061214
          smk060  0.003695016 0.0002287261  16.154762
(Dispersion Parameter for Robust Poisson family taken to be 0.8436161
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5965.521 on 6042.0178932 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-89

```
Call: gam(formula = all75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk090
, family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q     Max
 -2.941721 -0.7670835 -0.05083155 0.6184031 2.84422
Coefficients:
                        Value   Std. Error    t value
     (Intercept)  1.645777077 0.0581125543  28.320508
lo(Date, 0.0274)  6.540395837 0.4195998935  15.587220
   factor(wday)2 -0.034100732 0.0174283514  -1.956624
   factor(wday)3 -0.021728634 0.0173678986  -1.251080
   factor(wday)4 -0.034365232 0.0174378987  -1.970721
   factor(wday)5 -0.019304477 0.0173478254  -1.112789
   factor(wday)6 -0.038106389 0.0174502317  -2.183718
   factor(wday)7 -0.030183670 0.0173786478  -1.736825
 lo(temp05, 0.9) -3.899620159 0.4301896053  -9.064887
        relhum01  0.001873945 0.0006851579   2.735056
          smk090  0.003864185 0.0002565999  15.059184
(Dispersion Parameter for Robust Poisson family taken to be 0.8428073
    Null Deviance: 7591.064 on 6118 degrees of freedom
Residual Deviance: 5965.391 on 6042.0231411 degrees of freedom
```

Number of Fisher Scoring Iterations: 4

Appendix XIII

MODEL OUTPUTS FOR MEDIUM TERM EXPOSURE

RESPIRATORY MORTALITY

AGE 0-64

Lag 0-13

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk014,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk014, family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -1.452059 -0.6755224 -0.5803149 -0.4509607 3.101523
Coefficients:          Value   Std. Error     t value
     (Intercept)  -1.986201300 0.3272661304 -6.06907075
lo(Date, 0.0274) -16.498505396 2.1432108891 -7.69803171
   factor(wday)2  -0.009893152 0.1007935119 -0.09815267
   factor(wday)3   0.086703641 0.0984002443  0.88113238
   factor(wday)4   0.058117150 0.0991247846  0.58630291
   factor(wday)5   0.092036480 0.0984069847  0.93526369
   factor(wday)6   0.011751016 0.1002896049  0.11717083
   factor(wday)7   0.060521302 0.0990265278  0.61116251
 lo(temp05, 0.9)  -2.086164416 2.3536671300 -0.88634641
        relhum01   0.004139660 0.0039162236  1.05705404
          smk014   0.003818113 0.0008117244  4.70370586
(Dispersion Parameter for Robust Poisson family taken to be 0.9327412
```

Lag 0-24

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
25, family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min          1Q      Median          3Q       Max
 -1.392978 -0.6734996 -0.5783976 -0.4499455 3.087819
Coefficients:
                        Value   Std. Error     t value
     (Intercept)  -1.998012775 0.3284726380 -6.08273732
lo(Date, 0.0274) -14.269138426 2.1928713951 -6.50705666
   factor(wday)2  -0.013178765 0.1011794927 -0.13025135
   factor(wday)3   0.094068205 0.0985015719  0.95499191
   factor(wday)4   0.053018183 0.0994784144  0.53296168
   factor(wday)5   0.072005950 0.0990218602  0.72717226
   factor(wday)6  -0.003411680 0.1008473804 -0.03383013
   factor(wday)7   0.065602676 0.0991177280  0.66186622
 lo(temp05, 0.9)  -1.374356487 2.3628099208 -0.58166189
        relhum01   0.003466097 0.0039300782  0.88194086
          smk025   0.006019572 0.0009038617  6.65983758
(Dispersion Parameter for Robust Poisson family taken to be 0.9315428
    Null Deviance: 4649.375 on 6094 degrees of freedom
Residual Deviance: 4252.476 on 6017.638513 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-29

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smkl
ag030,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.382033 -0.6744919 -0.5782741 -0.4505645 3.080189
Coefficients:
                         Value   Std. Error     t value
     (Intercept)  -2.025438346 0.3278657504 -6.17764540
lo(Date, 0.0274) -14.664327828 2.1705066687 -6.75617727
   factor(wday)2  -0.010923945 0.1008938150 -0.10827171
   factor(wday)3   0.084296534 0.0985105516  0.85571071
   factor(wday)4   0.055481014 0.0992298001  0.55911645
   factor(wday)5   0.088815473 0.0985243602  0.90145698
   factor(wday)6   0.009469779 0.1004089372  0.09431211
   factor(wday)7   0.060006482 0.0991406830  0.60526597
 lo(temp05, 0.9)  -2.052120763 2.3671941671 -0.86690006
        relhum01   0.003671980 0.0039212781  0.93642438
       smklag030   0.006348190 0.0009356436  6.78483751
(Dispersion Parameter for Robust Poisson family taken to be 0.9342686
    Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4283.801 on 6041.348975 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-34

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk035,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
35,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
-1.388245 -0.6724632 -0.5775732 -0.449234 3.087505
Coefficients:
                          Value   Std. Error    t value
      (Intercept)  -2.054786355 0.3290758630 -6.24411142
lo(Date, 0.0274) -13.241188792 2.2165248075 -5.97385093
   factor(wday)2  -0.013178947 0.1012064791 -0.13021841
   factor(wday)3   0.086811059 0.0987101282  0.87945442
   factor(wday)4   0.048676147 0.0996612295  0.48841608
   factor(wday)5   0.068695404 0.0992414806  0.69220455
   factor(wday)6  -0.006148687 0.1010645351 -0.06083921
   factor(wday)7   0.066690861 0.0991904545  0.67235161
 lo(temp05, 0.9)  -1.257168572 2.3814349107 -0.52790381
        relhum01   0.003707688 0.0039288631  0.94370508
          smk035   0.007278222 0.0009663121  7.53195778
(Dispersion Parameter for Robust Poisson family taken to be 0.9334718
    Null Deviance: 4641.037 on 6084 degrees of freedom
Residual Deviance: 4245.325 on 6007.7287901 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-39

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk040,+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
40,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -1.409324 -0.6717297 -0.5772609 -0.4489503 3.088369
Coefficients:
                      Value  Std. Error     t value
     (Intercept)  -2.063829665 0.328817208 -6.27652573
lo(Date, 0.0274) -12.948435158 2.221291839 -5.82923636
   factor(wday)2  -0.013154023 0.101219786 -0.12995505
   factor(wday)3   0.087639864 0.098701688  0.88792670
   factor(wday)4   0.048925149 0.099668108  0.49088068
   factor(wday)5   0.066488986 0.099272335  0.66976349
   factor(wday)6  -0.009484702 0.101054829 -0.09385699
   factor(wday)7   0.063470779 0.099211378  0.63975302
 lo(temp05, 0.9)  -1.322958304 2.391480895 -0.55319627
        relhum01   0.003590537 0.003922066  0.91547079
          smk040   0.007941428 0.000992790  7.99910202
(Dispersion Parameter for Robust Poisson family taken to be 0.9339025
    Null Deviance: 4638.724 on 6079 degrees of freedom
Residual Deviance: 4241.806 on 6002.7765609 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-44

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
45,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -1.412105 -0.6715675 -0.5764247 -0.449901 3.089741
Coefficients:
                          Value  Std. Error    t value
      (Intercept)  -2.093550894 0.327835408 -6.38598162
lo(Date, 0.0274) -12.742077607 2.183771516 -5.83489505
    factor(wday)2  -0.008753761 0.100828098 -0.08681866
    factor(wday)3   0.083436388 0.098498517  0.84708268
    factor(wday)4   0.054659952 0.099205227  0.55097855
    factor(wday)5   0.087200883 0.098505886  0.88523525
    factor(wday)6   0.007001763 0.100420129  0.06972470
    factor(wday)7   0.057809906 0.099144184  0.58308923
 lo(temp05, 0.9)  -1.221921237 2.386352791 -0.51204551
         relhum01   0.003497343 0.003909251  0.89463260
           smk045   0.009086291 0.001004747  9.04336249
(Dispersion Parameter for Robust Poisson family taken to be 0.934632
    Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4278.971 on 6041.3217591 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-49

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk050,+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk0
50,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.372797 -0.6696928 -0.5770464 -0.4488487 3.089373
Coefficients:
                         Value  Std. Error     t value
     (Intercept)  -2.152232289 0.331333618 -6.49566531
lo(Date, 0.0274) -11.878805742 2.241022562 -5.30061854
   factor(wday)2   0.002012675 0.101604715  0.01980887
   factor(wday)3   0.100669852 0.099138249  1.01544916
   factor(wday)4   0.062784540 0.100084540  0.62731507
   factor(wday)5   0.084440614 0.099629705  0.84754456
   factor(wday)6   0.006873653 0.101510043  0.06771402
   factor(wday)7   0.070425834 0.099893746  0.70500744
 lo(temp05, 0.9)  -0.855474216 2.405607273 -0.35561674
        relhum01   0.004071150 0.003940281  1.03321330
          smk050   0.009132040 0.001046812  8.72366914
(Dispersion Parameter for Robust Poisson family taken to be 0.9336539
    Null Deviance: 4626.683 on 6069 degrees of freedom
Residual Deviance: 4230.066 on 5992.8888773 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-54

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk055,+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk055,family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.340769 -0.6697398 -0.5762812 -0.4486286 3.088681
Coefficients:
                         Value  Std. Error     t value
     (Intercept)  -2.169216019 0.331729907 -6.53910297
lo(Date, 0.0274) -11.205109924 2.246891776 -4.98693797
   factor(wday)2   0.005572666 0.101591871  0.05485346
   factor(wday)3   0.104582951 0.099129316  1.05501536
   factor(wday)4   0.066117424 0.100086408  0.66060343
   factor(wday)5   0.088642610 0.099603991  0.88995038
   factor(wday)6   0.002915144 0.101658392  0.02867588
   factor(wday)7   0.070519125 0.099881521  0.70602774
 lo(temp05, 0.9)  -0.501177940 2.411842887 -0.20779875
        relhum01   0.003895118 0.003940650  0.98844564
          smk055   0.010129215 0.001073032  9.43980443
(Dispersion Parameter for Robust Poisson family taken to be 0.9332885
    Null Deviance: 4623.442 on 6064 degrees of freedom
Residual Deviance: 4224.339 on 5987.9366901 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-59

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk060,+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk060,family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -1.280395 -0.6728251 -0.5769626 -0.4490738 3.092206
Coefficients:
                      Value  Std. Error     t value
     (Intercept)  -2.148043506 0.329132562 -6.52637799
lo(Date, 0.0274) -12.473359175 2.197926803 -5.67505668
   factor(wday)2  -0.007754098 0.100893867 -0.07685401
   factor(wday)3   0.085199373 0.098578581  0.86427875
   factor(wday)4   0.056555621 0.099271295  0.56970770
   factor(wday)5   0.090919538 0.098527138  0.92278675
   factor(wday)6   0.006616631 0.100532165  0.06581606
   factor(wday)7   0.059434244 0.099197493  0.59915066
 lo(temp05, 0.9)  -1.259448337 2.411640386 -0.52223721
        relhum01   0.003941717 0.003909163  1.00832776
          smk060   0.009712829 0.001100545  8.82546840
(Dispersion Parameter for Robust Poisson family taken to be 0.9351456
Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4282.357 on 6041.3307751 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

Lag 0-89

```
lresp_gam(formula=resp064~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk090,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp)
Call: gam(formula = resp064 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk090,family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q     Max
 -1.239654 -0.6738513 -0.5779157 -0.4491554 3.10233
Coefficients:
                         Value  Std. Error     t value
     (Intercept)  -2.296173751 0.332452128 -6.90678013
lo(Date, 0.0274) -10.686344017 2.225546082 -4.80167277
   factor(wday)2  -0.008671488 0.100762065 -0.08605906
   factor(wday)3   0.084148915 0.098453747  0.85470505
   factor(wday)4   0.056723867 0.099147338  0.57211690
   factor(wday)5   0.090721456 0.098420961  0.92176966
   factor(wday)6   0.006887791 0.100389996  0.06861034
   factor(wday)7   0.058616552 0.099069069  0.59167360
 lo(temp05, 0.9)  -0.128995386 2.440668421 -0.05285248
        relhum01   0.004771315 0.003908465  1.22076449
          smk090   0.012655015 0.001279763  9.88856225
(Dispersion Parameter for Robust Poisson family taken to be 0.9332464
    Null Deviance: 4687.268 on 6118 degrees of freedom
Residual Deviance: 4278.555 on 6041.3369891 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

age group 65-74

Lag 0-13

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk014, data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk014, family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q        Max
 -2.044927 -0.9123462 -0.7794377 0.616952 3.329427
Coefficients:
                        Value   Std. Error    t value
     (Intercept) -0.892725745 0.2285315200 -3.9063572
lo(Date, 0.0274) -5.241609463 1.5703022125 -3.3379622
   factor(wday)2 -0.135359921 0.0696877459 -1.9423777
   factor(wday)3 -0.078151697 0.0686725052 -1.1380347
   factor(wday)4 -0.073609296 0.0686077381 -1.0729008
   factor(wday)5 -0.064549182 0.0684187960 -0.9434422
   factor(wday)6 -0.056644813 0.0682439172 -0.8300346
   factor(wday)7 -0.102121993 0.0690660456 -1.4786136
 lo(temp05, 0.9) -8.308461680 1.6670450695 -4.9839454
        relhum01  0.001107174 0.0027588722  0.4013138
          smk014  0.003145266 0.0005896554  5.3340754
(Dispersion Parameter for Robust Poisson family taken to be 0.9658387
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5730.253 on 6041.4464105 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-24

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
025,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.988612 -0.9035638 -0.7762991 0.6153761 3.330711
Coefficients:
                        Value   Std. Error    t value
     (Intercept) -0.9485967973 0.2285353566 -4.1507660
lo(Date, 0.0274) -3.3743478042 1.5966642500 -2.1133734
   factor(wday)2 -0.1328923784 0.0696616746 -1.9076828
   factor(wday)3 -0.0791719854 0.0687017275 -1.1524017
   factor(wday)4 -0.0757686981 0.0686297448 -1.1040213
   factor(wday)5 -0.0668407098 0.0683978717 -0.9772338
   factor(wday)6 -0.0582539753 0.0682122333 -0.8540107
   factor(wday)7 -0.1132687414 0.0692469250 -1.6357223
 lo(temp05, 0.9) -8.2656328687 1.6705743878 -4.9477790
        relhum01  0.0008406521 0.0027592172  0.3046705
          smk025  0.0056964381 0.0006561667  8.6813885
(Dispersion Parameter for Robust Poisson family taken to be 0.9642825
    Null Deviance: 6195.427 on 6094 degrees of freedom
Residual Deviance: 5688.37 on 6017.6810349 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-29

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 +smklag030, family = robust(poisson), data =
longterm, na.action = na.omit)
Deviance Residuals:
      Min          1Q      Median          3Q      Max
 -2.001702 -0.9066335 -0.7776394 0.6225171 3.333792
Coefficients:
                         Value   Std. Error     t value
     (Intercept) -0.9274228074 0.2286995740 -4.05520129
lo(Date, 0.0274) -2.3066665815 1.5976507037 -1.44378654
   factor(wday)2 -0.1364344997 0.0697256383 -1.95673361
   factor(wday)3 -0.0807637817 0.0687199897 -1.17525893
   factor(wday)4 -0.0762583386 0.0686470331 -1.11087596
   factor(wday)5 -0.0673968818 0.0684609106 -0.98445786
   factor(wday)6 -0.0584409388 0.0682836692 -0.85585528
   factor(wday)7 -0.1029949154 0.0691168209 -1.49015701
 lo(temp05, 0.9) -7.4777282766 1.6755085672 -4.46296034
        relhum01  0.0002529659 0.0027600118  0.09165392
       smklag030  0.0065179492 0.0006764748  9.63516980
(Dispersion Parameter for Robust Poisson family taken to be 0.9666477
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5719.468 on 6041.3987464 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

Lag 0-34

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk035,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
035,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.986318 -0.9019329 -0.7762215 0.6208872 3.333409
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.9933425039 0.2283580425  -4.3499344
lo(Date, 0.0274) -1.5687559638 1.6167520734  -0.9703133
   factor(wday)2 -0.1233702294 0.0697089087  -1.7697914
   factor(wday)3 -0.0698514409 0.0687546283  -1.0159526
   factor(wday)4 -0.0649962360 0.0686817867  -0.9463387
   factor(wday)5 -0.0634554400 0.0686321725  -0.9245728
   factor(wday)6 -0.0472336683 0.0683225406  -0.6913336
   factor(wday)7 -0.1039168703 0.0693502540  -1.4984353
 lo(temp05, 0.9) -7.7145419899 1.6798549644  -4.5923857
        relhum01  0.0006260583 0.0027508002   0.2275914
          smk035  0.0073747543 0.0006979077  10.5669473
(Dispersion Parameter for Robust Poisson family taken to be 0.961666
    Null Deviance: 6172.911 on 6084 degrees of freedom
Residual Deviance: 5665.336 on 6007.7704941 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-39

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk040,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
040,  family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -2.071369 -0.9022197 -0.7762093 0.6234139 3.330457
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -1.0128271582 0.2285381065  -4.4317649
lo(Date, 0.0274) -1.2212947781 1.6285231677  -0.7499401
   factor(wday)2 -0.1233046371 0.0698204828  -1.7660238
   factor(wday)3 -0.0719699835 0.0689033332  -1.0445066
   factor(wday)4 -0.0624357137 0.0687475561  -0.9081881
   factor(wday)5 -0.0645457722 0.0687341624  -0.9390639
   factor(wday)6 -0.0488613424 0.0683913753  -0.7144372
   factor(wday)7 -0.1034680467 0.0694003846  -1.4908858
 lo(temp05, 0.9) -7.7248933842 1.6868444598  -4.5794936
        relhum01  0.0007618756 0.0027499409   0.2770516
          smk040  0.0076240396 0.0007205838  10.5803656
```

lag 0-44>

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
045,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.998661 -0.9048558 -0.7774581 0.621457 3.339483
Coefficients:
                         Value   Std. Error     t value
     (Intercept) -0.9861554845 0.2284472180  -4.3167761
lo(Date, 0.0274) -1.0892048810 1.6122171753  -0.6755944
   factor(wday)2 -0.1343667692 0.0697055965  -1.9276324
   factor(wday)3 -0.0791711426 0.0686954580  -1.1524946
   factor(wday)4 -0.0759056008 0.0686379675  -1.1058836
   factor(wday)5 -0.0667128887 0.0684365262  -0.9748141
   factor(wday)6 -0.0581523595 0.0682769599  -0.8517128
   factor(wday)7 -0.1017030603 0.0690817984  -1.4722121
 lo(temp05, 0.9) -7.3142925004 1.6911493564  -4.3250423
        relhum01  0.0003891686 0.0027481286   0.1416122
          smk045  0.0080173515 0.0007384254  10.8573614
(Dispersion Parameter for Robust Poisson family taken to be 0.9661066
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5719.426 on 6041.3887717 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-49

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk050,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
050,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q     Median         3Q      Max
 -1.934835 -0.9018246 -0.7763523 0.6196111 3.330977
Coefficients:
                         Value   Std. Error      t value
     (Intercept) -0.9820791025 0.2293627751  -4.28177197
lo(Date, 0.0274) -0.9146109721 1.6407710339  -0.55742755
   factor(wday)2 -0.1265073867 0.0699276447  -1.80911837
   factor(wday)3 -0.0724349002 0.0689544245  -1.05047502
   factor(wday)4 -0.0660456267 0.0688636431  -0.95907831
   factor(wday)5 -0.0633419495 0.0687810561  -0.92092144
   factor(wday)6 -0.0448908905 0.0684424228  -0.65589277
   factor(wday)7 -0.0996099327 0.0694489617  -1.43428973
 lo(temp05, 0.9) -7.8905545417 1.6988381034  -4.64467716
        relhum01  0.0002173182 0.0027525943   0.07895033
          smk050  0.0080687968 0.0007678598  10.50816459
(Dispersion Parameter for Robust Poisson family taken to be 0.9626481
    Null Deviance: 6159.89 on 6069 degrees of freedom
Residual Deviance: 5659.321 on 5992.9614147 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-54

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk055,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
055,  family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q    Median        3Q       Max
 -1.875479 -0.9017503 -0.7766021 0.6192909 3.338348
Coefficients:
                         Value   Std. Error     t value
     (Intercept) -1.0021685231 0.2297203284  -4.3625592
lo(Date, 0.0274) -0.6060887911 1.6521454412  -0.3668495
   factor(wday)2 -0.1244663395 0.0699312937  -1.7798375
   factor(wday)3 -0.0726181006 0.0690008013  -1.0524240
   factor(wday)4 -0.0695825430 0.0689694666  -1.0088891
   factor(wday)5 -0.0664409639 0.0688750510  -0.9646594
   factor(wday)6 -0.0439067618 0.0684455336  -0.6414847
   factor(wday)7 -0.1007474209 0.0694518879  -1.4506074
 lo(temp05, 0.9) -7.8588282379 1.7048187902  -4.6097734
        relhum01  0.0003842132 0.0027538421   0.1395190
          smk055  0.0082769460 0.0007923968  10.4454562
(Dispersion Parameter for Robust Poisson family taken to be 0.9628544
    Null Deviance: 6151.918 on 6064 degrees of freedom
Residual Deviance: 5654.123 on 5988.0306776 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-59>

```
lresp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+r
elhum01+smk060,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
060,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
     Min       1Q    Median       3Q      Max
 -1.8328 -0.905866 -0.7770596 0.620376 3.342691
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -1.026601667 0.2291340551  -4.4803539
lo(Date, 0.0274) -0.704920859 1.6261598243  -0.4334881
   factor(wday)2 -0.134812894 0.0697241856  -1.9335169
   factor(wday)3 -0.078076011 0.0687059244  -1.1363796
   factor(wday)4 -0.076659889 0.0686845385  -1.1161157
   factor(wday)5 -0.066623503 0.0684544007  -0.9732538
   factor(wday)6 -0.058101382 0.0682885101  -0.8508222
   factor(wday)7 -0.102445730 0.0691025305  -1.4825178
 lo(temp05, 0.9) -7.312848548 1.7093192872  -4.2782227
        relhum01  0.000665866 0.0027449727   0.2425765
          smk060  0.008634996 0.0008092561  10.6702883
(Dispersion Parameter for Robust Poisson family taken to be 0.966714
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5724.285 on 6041.3962989 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-89

```
lesp2_gam(formula=resp6574~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+re
lhum01+smk090,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp2)
Call: gam(formula = resp6574 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk
090,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q     Median         3Q      Max
 -1.764857 -0.9081507 -0.7761343 0.6095188 3.342547
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -1.157249186 0.2317718376  -4.9930535
lo(Date, 0.0274)  0.522724786 1.6499724425   0.3168082
   factor(wday)2 -0.135289432 0.0696875442  -1.9413718
   factor(wday)3 -0.078199040 0.0686653401  -1.1388430
   factor(wday)4 -0.076749047 0.0686632162  -1.1177607
   factor(wday)5 -0.064733529 0.0684107868  -0.9462474
   factor(wday)6 -0.057516292 0.0682504257  -0.8427243
   factor(wday)7 -0.102560223 0.0690684402  -1.4849072
 lo(temp05, 0.9) -6.731775730 1.7274096740  -3.8970349
        relhum01  0.001629379 0.0027440627   0.5937835
          smk090  0.010486440 0.0009337224  11.2307892
(Dispersion Parameter for Robust Poisson family taken to be 0.9660144
    Null Deviance: 6224.968 on 6118 degrees of freedom
Residual Deviance: 5722.204 on 6041.4025632 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

age 75 and over

lag 0-13

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk014,data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk01
4,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min        1Q      Median        3Q       Max
 -2.315507 -1.26454 -0.09715181 0.5411767 3.232825
Coefficients:
                        Value   Std. Error    t value
     (Intercept) -0.333160224 0.1417409036 -2.3504875
lo(Date, 0.0274)  1.552782824 0.9806775326  1.5833776
   factor(wday)2 -0.017045182 0.0430035926 -0.3963665
   factor(wday)3 -0.079543205 0.0436462568 -1.8224519
   factor(wday)4 -0.008219164 0.0429160196 -0.1915174
   factor(wday)5 -0.057145615 0.0434806953 -1.3142756
   factor(wday)6  0.011939533 0.0427609065  0.2792161
   factor(wday)7 -0.048872503 0.0433455616 -1.1275088
 lo(temp05, 0.9) -7.370625904 1.0289076710 -7.1635445
        relhum01  0.005459701 0.0017022230  3.2073948
          smk014  0.003326604 0.0003733231  8.9107904
(Dispersion Parameter for Robust Poisson family taken to be 0.9436339
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 7014.811 on 6041.5852847 degrees of freedom
Number of Fisher Scoring Iterations: 5
```

lag 0-24

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk025,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk02
5,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q     Max
 -2.336255 -1.262019 -0.08928819 0.5369462 3.22458
Coefficients:
                        Value   Std. Error      t value
     (Intercept) -0.340581912 0.1392393999  -2.44601680
lo(Date, 0.0274)  3.966875289 0.9846903092   4.02855116
   factor(wday)2 -0.023665630 0.0421936647  -0.56088112
   factor(wday)3 -0.093543187 0.0429353911  -2.17869653
   factor(wday)4 -0.016044788 0.0421284909  -0.38085360
   factor(wday)5 -0.063206663 0.0426317111  -1.48262084
   factor(wday)6  0.003809869 0.0419088455   0.09090846
   factor(wday)7 -0.056877210 0.0425361005  -1.33715149
 lo(temp05, 0.9) -7.144595453 1.0145649966  -7.04202833
        relhum01  0.004659634 0.0016723769   2.78623444
          smk025  0.005762168 0.0004099074  14.05724392
(Dispersion Parameter for Robust Poisson family taken to be 0.9249039
    Null Deviance: 8079.648 on 6094 degrees of freedom
Residual Deviance: 6976.935 on 6017.8606606 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-29

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smklag030,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smkla
g030,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.311263 -1.258413 -0.08642745 0.5309181 3.211308
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.380839102 0.1387069420  -2.7456384
lo(Date, 0.0274)  4.408268374 0.9729752922   4.5307095
   factor(wday)2 -0.021473630 0.0419766876  -0.5115609
   factor(wday)3 -0.087392292 0.0426608481  -2.0485362
   factor(wday)4 -0.016333122 0.0419413252  -0.3894279
   factor(wday)5 -0.065111935 0.0424821163  -1.5326905
   factor(wday)6  0.006894161 0.0417184772   0.1652544
   factor(wday)7 -0.054809346 0.0423487674  -1.2942371
 lo(temp05, 0.9) -6.865575258 1.0128373826  -6.7785563
        relhum01  0.004797859 0.0016649862   2.8816209
       smklag030  0.006740940 0.0004192027  16.0803839
(Dispersion Parameter for Robust Poisson family taken to be 0.9198683
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 6982.394 on 6041.5521423 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-34

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk035,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk03
5,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min        1Q      Median        3Q      Max
 -2.273163 -1.260521 -0.08548488 0.5308331 3.217523
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.392584944 0.1392356226  -2.8195726
lo(Date, 0.0274)  5.369128901 0.9940939981   5.4010274
   factor(wday)2 -0.022896465 0.0421493557  -0.5432222
   factor(wday)3 -0.094345243 0.0428990665  -2.1992377
   factor(wday)4 -0.016468413 0.0421053166  -0.3911243
   factor(wday)5 -0.063940702 0.0426345465  -1.4997392
   factor(wday)6  0.006964911 0.0418773598   0.1663169
   factor(wday)7 -0.057839960 0.0425280003  -1.3600442
 lo(temp05, 0.9) -6.643416998 1.0194455506  -6.5166963
        relhum01  0.004714613 0.0016686510   2.8254041
          smk035  0.007304308 0.0004361166  16.7485223
(Dispersion Parameter for Robust Poisson family taken to be 0.9220125
    Null Deviance: 8076.84 on 6084 degrees of freedom
Residual Deviance: 6959.062 on 6007.9527262 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-39

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk040,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04
0,
     family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.243266 -1.259903 -0.08778731 0.5298809 3.222258
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.405135706 0.1394148735  -2.9059719
lo(Date, 0.0274)  5.703336989 0.9996184587   5.7055139
   factor(wday)2 -0.023744523 0.0422076124  -0.5625649
   factor(wday)3 -0.095395103 0.0429629138  -2.2204058
   factor(wday)4 -0.015561753 0.0421471455  -0.3692244
   factor(wday)5 -0.065354785 0.0426882852  -1.5309771
   factor(wday)6  0.004932089 0.0419100754   0.1176827
   factor(wday)7 -0.059507035 0.0425700791  -1.3978606
 lo(temp05, 0.9) -6.547127524 1.0233728214  -6.3975976
        relhum01  0.004733300 0.0016691639   2.8357313
          smk040  0.007701817 0.0004492617  17.1432749
(Dispersion Parameter for Robust Poisson family taken to be 0.9238647
    Null Deviance: 8073.482 on 6079 degrees of freedom
Residual Deviance: 6959.243 on 6003.010965 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-44

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk045,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)

Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk04
5,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min       1Q     Median       3Q      Max
 -2.205635 -1.257438 -0.0910844 0.5334555 3.21806
Coefficients:
                          Value   Std. Error    t value
       (Intercept) -0.434890930 0.1388935232  -3.1311102
lo(Date, 0.0274)  5.433805516 0.9811835106   5.5380115
   factor(wday)2 -0.018930959 0.0419941191  -0.4508002
   factor(wday)3 -0.086996586 0.0426918285  -2.0377807
   factor(wday)4 -0.012875862 0.0419390577  -0.3070136
   factor(wday)5 -0.064333787 0.0425059751  -1.5135234
   factor(wday)6  0.008843326 0.0417270244   0.2119328
   factor(wday)7 -0.055010539 0.0423785688  -1.2980745
 lo(temp05, 0.9) -6.719635057 1.0211927037  -6.5801832
        relhum01  0.004948234 0.0016618826   2.9774871
          smk045  0.008113981 0.0004581102  17.7118530
(Dispersion Parameter for Robust Poisson family taken to be 0.9211948
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 6989.181 on 6041.5464342 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-49>

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk050,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk05
0,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.195348 -1.259068 -0.08391701 0.5320668 3.223989
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.442606197 0.1400010286  -3.1614496
lo(Date, 0.0274)  6.256525057 1.0082583827   6.2052795
   factor(wday)2 -0.023044089 0.0422493088  -0.5454312
   factor(wday)3 -0.096513125 0.0430187898  -2.2435109
   factor(wday)4 -0.016408354 0.0422009663  -0.3888147
   factor(wday)5 -0.063643157 0.0427291740  -1.4894544
   factor(wday)6  0.008965445 0.0419495624   0.2137196
   factor(wday)7 -0.061883303 0.0426742139  -1.4501334
 lo(temp05, 0.9) -6.499276362 1.0295716855  -6.3126021
        relhum01  0.004918990 0.0016718274   2.9422834
          smk050  0.008439175 0.0004766487  17.7052304
(Dispersion Parameter for Robust Poisson family taken to be 0.9253073
    Null Deviance: 8059.54 on 6069 degrees of freedom
Residual Deviance: 6951.405 on 5993.134193 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-54

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk055,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk05
5,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
      Min         1Q      Median         3Q      Max
 -2.24811 -1.259163 -0.08501087 0.5317098 3.229253
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.454041518 0.1402849885  -3.2365652
lo(Date, 0.0274)  6.517930536 1.0131989960   6.4330211
   factor(wday)2 -0.022056136 0.0423001228  -0.5214201
   factor(wday)3 -0.097129053 0.0430956713  -2.2538007
   factor(wday)4 -0.014479521 0.0422503157  -0.3427080
   factor(wday)5 -0.062602930 0.0427801773  -1.4633630
   factor(wday)6  0.009889069 0.0419976433   0.2354672
   factor(wday)7 -0.062476235 0.0427240670  -1.4623195
 lo(temp05, 0.9) -6.411467507 1.0339905352  -6.2007023
        relhum01  0.004914522 0.0016730945   2.9373846
          smk055  0.008821585 0.0004917552  17.9389752
(Dispersion Parameter for Robust Poisson family taken to be 0.9273409
    Null Deviance: 8054.229 on 6064 degrees of freedom
Residual Deviance: 6950.267 on 5988.1952268 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

lag 0-59

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk060,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk06
0,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q     Max
 -2.288728 -1.254032 -0.08840559 0.5299177 3.21788
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.490308289 0.1393506562  -3.5185216
lo(Date, 0.0274)  6.080761969 0.9884691504   6.1516963
   factor(wday)2 -0.016609972 0.0420080682  -0.3953996
   factor(wday)3 -0.083450264 0.0427090232  -1.9539258
   factor(wday)4 -0.009193324 0.0419553526  -0.2191216
   factor(wday)5 -0.061763972 0.0425232647  -1.4524748
   factor(wday)6  0.011290371 0.0417510215   0.2704214
   factor(wday)7 -0.053071057 0.0424046251  -1.2515393
 lo(temp05, 0.9) -6.521555028 1.0312138513  -6.3241538
        relhum01  0.005234643 0.0016601850   3.1530483
          smk060  0.009141229 0.0005004703  18.2652781
(Dispersion Parameter for Robust Poisson family taken to be 0.9209723
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 6991.681 on 6041.5498727 degrees of freedom
Number of Fisher Scoring Iterations: 4
```

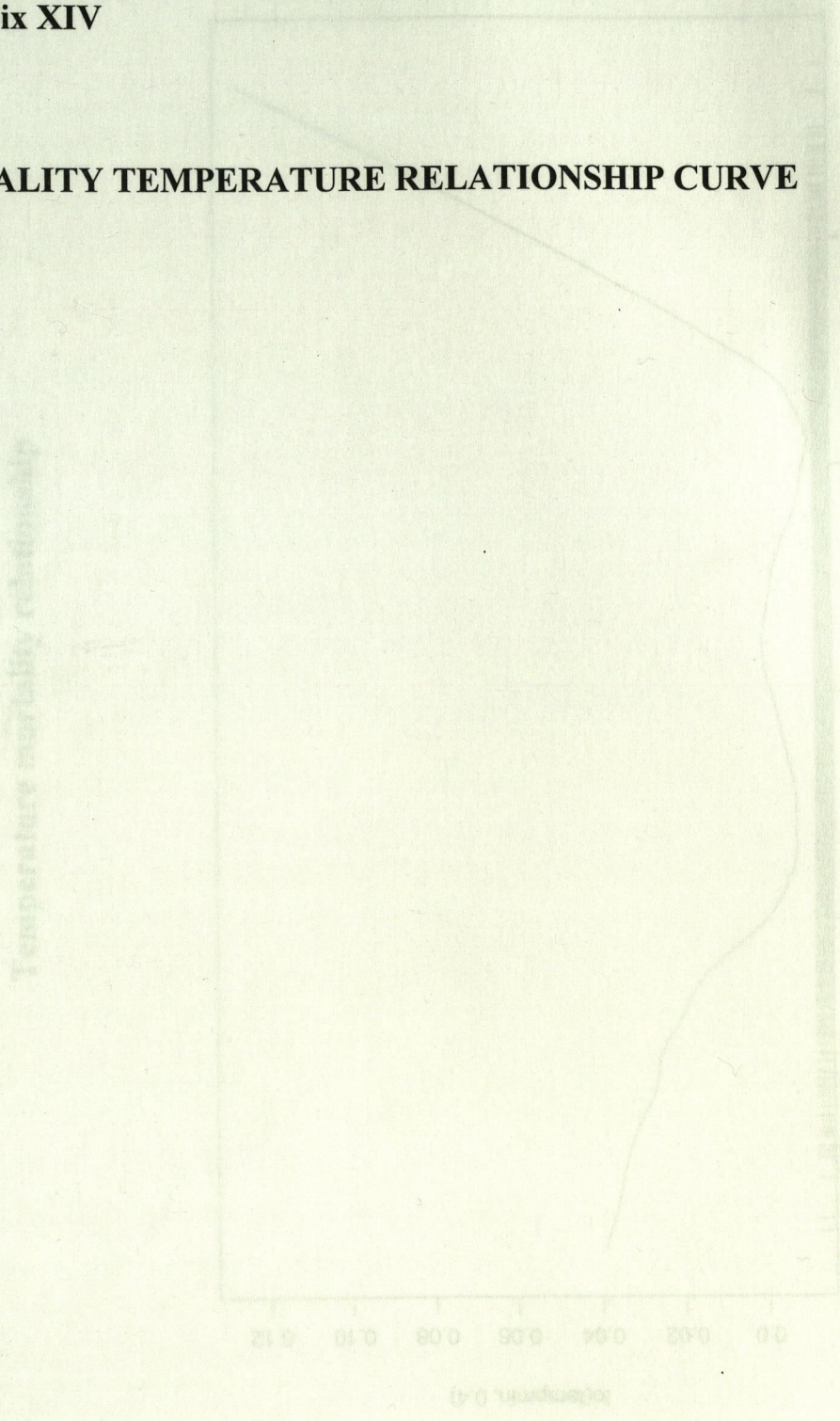
lag 0-89

```
lresp3_gam(formula=resp75~lo(Date,.0274)+factor(wday)+lo(temp05,.9)+rel
hum01+smk090,
+ data=longterm,family=robust(poisson),na.action=na.omit)
> summary.glm(lresp3)
Call: gam(formula = resp75 ~ lo(Date, 0.0274) + factor(wday) +
lo(temp05, 0.9) + relhum01 + smk09
0,family = robust(poisson), data = longterm, na.action = na.omit)
Deviance Residuals:
       Min         1Q      Median         3Q      Max
 -2.275898 -1.253574 -0.09535528 0.5321855 3.233082
Coefficients:
                        Value   Std. Error     t value
     (Intercept) -0.608920512 0.1438297918  -4.2336188
lo(Date, 0.0274)  6.897934466 1.0219329973   6.7498892
   factor(wday)2 -0.016054811 0.0428602079  -0.3745855
   factor(wday)3 -0.078992816 0.0435036703  -1.8157736
   factor(wday)4 -0.004633224 0.0427497767  -0.1083801
   factor(wday)5 -0.057456676 0.0433376981  -1.3257898
   factor(wday)6  0.013215710 0.0426132675   0.3101313
   factor(wday)7 -0.049886145 0.0432247648  -1.1541103
 lo(temp05, 0.9) -5.916115997 1.0641714230  -5.5593637
        relhum01  0.006206273 0.0016935979   3.6645496
          smk090  0.010560715 0.0005928354  17.8139084
(Dispersion Parameter for Robust Poisson family taken to be 0.938287
    Null Deviance: 8104.794 on 6118 degrees of freedom
Residual Deviance: 6997.27 on 6041.5525403 degrees of freedom
```

Number of Fisher Scoring Iterations: 5

Appendix XIV

MORTALITY TEMPERATURE RELATIONSHIP CURVE



Temperature mortality relationship

