

**A STUDY OF THE ASSOCIATION OF COLD WEATHER
AND ALL-CAUSE AND CAUSE-SPECIFIC MORTALITY
ON THE ISLAND OF IRELAND BETWEEN 1984 AND
2007**

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Master of Philosophy

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Abstract

Background:

This study explored the differences between the seasonal mortality rates (by age and gender) between the two jurisdictions (the Republic of Ireland (RoI) and Northern Ireland (NI)). The study assessed the relationship between cold temperatures and daily mortality, and assessed for effect modification of the cold weather-mortality relationship by age and gender.

Methods:

Mortality rates were calculated for each cause-specific mortality group during various seasons in both jurisdictions. A time-stratified case-crossover approach was applied to examine the cold weather-mortality relationship, 1984-2007. The daily mortality risk was explored in association with exposure to daily maximum temperatures on the same day and up to 6 weeks preceding death, during the winter months and extended cold period (October-March), using distributed lag models. Model stratification by age and gender assessed for modification of the cold weather-mortality relationship.

Results:

The winter mortality rates were significantly greater than the summer rates. NI experienced higher mortality from cardiovascular disease, respiratory disease and stroke. The impact of cold weather in the winter months persisted up to 35 days in the RoI, with a cumulative mortality increase for all-cause of 6.4% (95% CI: 4.8%-7.9%) with regards to every 1°C drop in the daily maximum temperature with similar associations for cardiovascular disease and stroke with twice as much for respiratory diseases. The associations were less pronounced and less persistent in NI.

Conclusions:

The study observed excess winter mortality. The cold weather-mortality associations increased with age with some suggestion of gender differences. There were strong cold weather-mortality associations in both jurisdictions, with suggestive differences in associations by age and gender. The findings suggest the potential contribution of societal differences, and require further exploration. These findings will hopefully contribute to the current efforts to modify fuel policy and reduce winter mortality in both jurisdictions.

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List of abbreviations

CI	Confidence Interval
RoI	Republic of Ireland
NI	Northern Ireland
ICD	International Classification of Diseases
CVD	Cardiovascular disease
CHD	Coronary heart disease
IHD	Ischemic heart disease
MI	Myocardial Infarction
RD	All respiratory disease
COPD	Chronic obstructive pulmonary disease
°C	Degrees Celsius
SD	Standard deviations
AMI	Acute myocardial infarction
DiffT1	The difference between the maximum temperature and the minimum temperature
DiffT2	The difference between the maximum temperature and the mean temperature
≥	Greater or equal to

1.0 INTRODUCTION

1.1 Background

The impact of weather on human health is increasingly being evidenced by epidemiological studies in the light of the effects of climate change (Michelozzi *et al.* 2007). Under the influences of global climate change, both mean temperature and temperature variability are expected to increase globally, likely affecting the increasing frequency of weather extremes, such as cold spells and heatwaves (Field *et al.* 2014; McMichael *et al.* 2006; Michelozzi *et al.* 2007). The Intergovernmental Panel on Climate Change (IPCC) has projected that in the coming decades, extreme weather events will become more frequent and more intense in some parts of the world and such events will impact upon health (Stocker *et al.* 2013). Recent record low temperatures in Northern Europe and the United States highlight the potential health and societal impacts of extreme winter weather, despite the rise in global average temperatures (Barnett *et al.* 2012; Staddon *et al.* 2014).

The nature and magnitude of the association between temperature and human health has been increasingly recognised (Basu and Samet 2002; Braga *et al.* 2001; Kunst *et al.* 1993; Martens 1998; Medina-Ramon *et al.* 2006; Patz *et al.* 2000; Samet *et al.* 1998). Mortality is known to be associated with meteorological conditions and to display a seasonal pattern, with excess mortality during the winter as well as during hot days in the summer (Kalkstein and Greene 1997). Generally, the health effects of extreme heat events are acute and some harvesting is observed, but the effects of extreme cold temperatures are generally more prolonged than heat without mortality displacement (Analitis *et al.* 2008; Kysely *et al.* 2009; Xie *et al.* 2013). Heatwaves in Europe in the summer of 2003 produced a rise in general mortality and concern in both the public and public health authorities (Kovats *et al.* 2004; Martinez-Navarro *et al.* 2004). However, the impact of cold weather on health has received much less attention despite its relationship with higher mortality and morbidity (Gomez-Acebo *et al.* 2010).

Exposure to cold temperatures contributes to a wide range of impacts on public health, such as increased mortality from cardiovascular, cerebrovascular and respiratory disease (Alberdi *et al.* 1998; Analitis *et al.* 2008; Anderson and Bell 2009; Armstrong 2006; Barnett *et al.* 2012; Braga *et al.* 2002; Carder *et al.* 2005; Donaldson and Keatinge

1997; Goodman *et al.* 2004; Gouveia *et al.* 2003; Hajat *et al.* 2005; Kunst *et al.* 1993; Pattenden *et al.* 2003; Yu *et al.* 2011). Although the association between cold weather and ill-health has been known for some time, populations across Europe still experience significantly more deaths in winter and non-winter months (Analitis *et al.* 2008; Fowler *et al.* 2014; Healy 2003; McKee 1989). Relative excess winter mortality was found to be highest in Southern Europe, the Republic of Ireland and the United Kingdom, where seasonality in mortality of 18-28% was calculated (Healy 2003). This is apparent at all ages but is greatest in relative and absolute terms in elderly people (Laake and Sverre 1996; Wilkinson *et al.* 2001). Much of the excess seems to be related to cold (Armstrong *et al.* 2000; Pattenden *et al.* 2003) yet Britain has a larger seasonal fluctuation in mortality than many other countries in continental Europe and Scandinavia despite having milder winters (McKee 1989). Relative seasonal variation in mortality appears lowest in countries with cold winters, such as Russia, Norway and Canada and is higher in Britain, Israel and Portugal where winters are milder (Curwen 1991; Douglas and Rawles 1999; Laake and Sverre 1996; McKee 1989). Although many countries currently experienced an increase in mortality during the winter, the magnitude of this increase varies considerably, suggesting that some winter excess may be avoidable (Davie *et al.* 2007).

In several temperate countries, associations between daily outdoor temperature mortality appear to have weakened in recent decades (Barnett 2007; Carson *et al.* 2006; euroMOMO 2013; Hajat *et al.* 2007; Lerchl 1998; Medina-Ramon and Schwartz 2007). However, it is still reported that in temperate countries, mortality rates are typically 10 to 30% higher during the winter compared to the warmer months (Aylin *et al.* 2001; Carson *et al.* 2006; Davie *et al.* 2007; Gemmell *et al.* 2000; Hajat *et al.* 2007; Healy 2003; McMichael *et al.* 2008; Wilkinson *et al.* 2001). The large death toll and the disruption associated with the cold weather in Central and Eastern Europe in the winter of 2005-2006 was a timely reminder of how poorly prepared many people were to the dangers of extreme cold temperatures (Hajat *et al.* 2007).

The immediate cause of most excess winter death is cardiovascular or respiratory disease, including seasonal respiratory infections, particularly in older people and those with chronic health conditions (Davie *et al.* 2007; Donaldson and Keatinge 1997; Rudge

and Gilchrist 2005; The Marmot Review Team 2011; Wilkinson *et al.* 2001). Mortality rates for cardiovascular and respiratory disease typically exhibit seasonal variation with the highest rates occurring in the winter months (Bowie and Jackson 2002). In temperate zones, all-cause mortality exhibits a marked seasonality with the highest number of deaths in the winter, and a lower number in the summer period (Nielsen *et al.* 2011). Excess winter mortality which is largely attributed to cardiovascular and respiratory diseases, might be related to seasonal changes in ambient exposures (temperature, humidity, ultraviolet light, air-pollution), diet behaviour, infectious disease transmission and other unidentified exposures (Barnard *et al.* 2008). Studies from European (Douglas *et al.* 1995; Haberman *et al.* 1981) and Asian (Enqueslassie *et al.* 1993; Marshall *et al.* 1988; Pan *et al.* 1995) countries have observed an increase in death rates from acute myocardial infarction (AMI) and stroke in winter.

The gradient of the low-temperature mortality relationship has declined progressively over the century, with the steepest temperature-related gradients observed for cardiovascular and respiratory deaths (Carson *et al.* 2006); the gradient of the decline in mortality was more moderate for respiratory disease (Carson *et al.* 2006). The vulnerability to cold has decreased over the course of the 20th century, despite the ageing of the population and a progressive increase in the prevalence of cardiorespiratory disease (Carson *et al.* 2006). Temperature-related mortality is of current scientific and public health interest in the United Kingdom (UK) (Carson *et al.* 2006) because of the persistently high number of excess winter deaths (Wilkinson *et al.* 2001) which is paradoxically higher in Britain than in many other colder-winter countries of continental Europe (Healy 2003).

1.2 Physiological effects of exposure to cold temperatures

Extreme temperatures are associated with daily mortality in numerous regions of the world; generally, non-linear relations (U, Y, or V shaped) have been observed with increased mortality at high or low temperatures (Braga *et al.* 2001; Kunst *et al.* 1993). There is an association between cardiovascular admissions and low temperatures (Schwartz *et al.* 2004). Cold weather alone causes striking short term increases in mortality, mainly from thrombotic and respiratory disease (Donaldson and Keatinge 1997). Some of the physiological consequences of the reduction in temperature,

thought to be involved in increased coronary risk, might be hazardous in heart failure (Stewart *et al.* 2002) and similar patterns were found with deaths from stroke (Sheth *et al.* 1999). The definition of 'cold environment' includes environmental conditions that activate the human thermoregulatory system (Raatikka *et al.* 2007). This system may be activated even at 15°C, although cold-induced sensations and physiologic responses usually develop at lower temperatures (Makinen 2006). The physiological and psychological aspects of cold are reflected in occupational health standards, which define cold as temperatures below 10 to 15°C (BS7915 1998). The combination of cold air, wind and wetness can quickly overwhelm human thermoregulation, the consequences ranging from impaired performance to death (Raatikka *et al.* 2007).

People expose themselves to cold ambient temperatures while commuting to work, while working and during recreation (Raatikka *et al.* 2007). Cold exposure may be due to environmental conditions, such as cold air, wind, rain, snow and ice or cold water immersion or contact with cold materials (Keim *et al.* 2002). Housing conditions and the ability to keep warm plays a key role in whether old people can survive the winter; and this is taken in conjunction with their general health to begin with (Goodman *et al.* 2011). The evidence indicates that cold may be a more important risk factor for morbidity and mortality than has been seen so far (Mercer 2003). For both clinical and public health reasons, it is important to estimate the prevalence of cold related complaints, symptoms and diseases in the general population (Raatikka *et al.* 2007). Patients with certain chronic medical conditions, such as cardiovascular and cerebrovascular diseases, diabetes mellitus and respiratory diseases, are most susceptible to cold (Makinen 2006).

Furthermore, it seems that long periods of cold weather appears to weaken those who are susceptible; and that if the cold weather continues, they may get progressively weaker and eventually die while if the temperature rises they may recover (Goodman *et al.* 2011). Excess winter mortality is not normally recorded as being from hypothermia, but it appears that cold weather interacts to trigger deaths from existing cardiovascular disease and/or respiratory conditions (Goodman *et al.* 2011).

Air temperature changes are associated with increased cardiovascular and respiratory

risk (Hampel *et al.* 2010). Temperature decrease is associated with change in several blood parameters; the complex interplay of blood markers at low temperatures may contribute to the observed associations between cold and cardiovascular mortality and morbidity (Hampel *et al.* 2010). Extreme cold temperatures are related to the increase in the heart rate, peripheral vasoconstriction, blood pressure, blood cholesterol levels, plasma fibrinogen concentrations and platelet viscosity (Ballester *et al.* 1997; Barnett *et al.* 2007; Carder *et al.* 2005). Exposure to winter conditions may induce physiologic stress including sympathetic activation, hypercoagulability and infection which can increase the incidence or case fatality of acute myocardial infarction and stroke (Douglas *et al.* 1995).

Environmental temperature has been implicated in seasonal variations in the evidence of acute myocardial infarction (AMI) and sudden death as these events peak in winter (Stewart *et al.* 2002). AMI deaths showed significant seasonal changes overall with deaths being higher in winter and lower in the summer with seasonal variation in mortality of nearly 10% (Sheth *et al.* 1999). Deaths such as myocardial ischaemia from increased work demands on the heart muscle or from increased formation of thrombus can occur in hours or days (Mercer 2003; Neild *et al.* 1994). A raised blood pressure in a cold environment has several adverse effects: it alters the ratio of myocardial oxygen supply to demand, and increases the ventricular wall stress, cardiac work, and oxygen requirements, but it also reduces mechanical efficiency and may impair coronary blood flow, particularly in people with fixed stenosis (Wilmshurst 1994). Consequently cold can precipitate myocardial ischaemia (Wilmshurst 1994). It is hypothesised that a wide range of blood markers are involved in the development of atherosclerosis leading to chronic as well as acute cardiovascular disease (Hampel *et al.* 2010). The excess number of coronary events in cold climates may also be related to blood clotting (Wilmshurst 1994). The plasma concentration of fibrinogen is inversely related to environmental temperature, but part of the rise in fibrinogen concentrations in the winter may be the result of seasonal respiratory infections (Elwood *et al.* 1993; Woodhouse *et al.* 1994).

For respiratory deaths, on the other hand, the timescale for manifestation of an adverse health effect may be longer – running into days or weeks with the progression to a full

blown exacerbation of chronic pulmonary disease taking longer (Carder *et al.* 2005; Yu *et al.* 2011a). Cold related increases in respiratory mortality are generally attributed to cross infection from increased indoor crowding during colder months and to the detrimental effect of exposure to cold temperatures, on the immune system's resistance to respiratory infections (The Eurowinter Group 1997).

Seasonal variations in fibrinogen concentrations due to temperature changes may be half that resulting from smoking (Elwood *et al.* 1993). In cold conditions the plasma concentrations of some clotting factors are increased, as a platelet count and in vitro platelet aggregation (Elwood *et al.* 1993; Keatinge *et al.* 1984; Neild *et al.* 1994; Woodhouse *et al.* 1994). Plasma volume and increased blood viscosity during the cold exposure also tend to promote thrombosis (Keatinge *et al.* 1984; Neild *et al.* 1994). Whether these factors have a role in atherogenesis is uncertain (Wilmshurst 1994). The cold can adversely alter plasma lipid concentrations, making abnormal thrombosis more likely and having a potential chronic atherogenic effect (Woodhead *et al.* 1994).

1.2.1 Aging

There is evidence that the effects of cold temperatures on mortality are pronounced in vulnerable groups such as the elderly and persons affected by chronic respiratory or cardiovascular diseases (Alberdi *et al.* 1998; Anderson and Bell 2009; Ballester *et al.* 1997; Curriero *et al.* 2002; Keatinge and Donaldson 2004; Kunst *et al.* 1993; Lin *et al.* 2011; O'Neill *et al.* 2003; Revich and Shaposhnikov 2008; Rocklov *et al.* 2011; The Eurowinter Group 1997). The effects of temperature on mortality are generally heterogeneous across socio-demographic strata such as age and gender (Basu and Samet 2002). Excess winter mortality, particularly in the older age groups is a well-known phenomenon, and most countries suffer from 5 to 30% excess winter mortality (Eng and Mercer 1998; Keatinge and Donaldson 1995; Kunst *et al.* 1993), mainly due to cardiovascular and respiratory diseases (Keatinge 2002; The Eurowinter Group 1997).

The ability of older adults to maintain core temperature is usually compromised (Yu *et al.* 2011a). The reduced sweat gland output, reduced skin blood flow, smaller increase in cardiac output and less redistribution of blood flow from renal and splanchnic circulations can consequently aggravate the injury to thermoregulation

(Basu 2009; Bouchama and Knochel 2002; McGeehin and Mirabelli 2001).

Aging is associated with an augmented systolic and mean blood pressure (BP) response to non-internal body temperature-reducing cold stress in humans and that these responses are strongly associated with increased levels of central arterial stiffness (Hess *et al.* 2009). Age-associated increases in arterial stiffness may be a critical factor underlying this augmented BP response in older individuals, as suggested by the strong correlation between these measures (Hess *et al.* 2009). Increased levels of central arterial stiffness may lead to greater increases in myocardial oxygen demand during cold exposure in older adults (Hess *et al.* 2009).

A pronounced age effect in seasonal variations of death rates was observed with winter increases as mortality from AMI and stroke being greater in the elderly compared with younger individuals (Sheth *et al.* 1999). The elderly, with their reduced physiologic reserve, may be more vulnerable to these influences than young people (Sheth *et al.* 1999). Aging is associated with augmented presser responses (systolic and mean BP) to non-internal body temperature-reducing cold stress in humans (Sheth *et al.* 1999).

1.3 Cold weather-mortality relationship

It is well-established that in many countries, there is significantly more mortality in winter than in summer (Goodman *et al.* 2011). Mortality presents seasonal dynamics with a maximum number of deaths in the winter and a minimum in the summer, which has been related to meteorological variables, mainly temperature (Alderson 1985; Mackenbach *et al.* 1992). Heatwaves in Europe in the summer of 2003 produced a rise in general mortality and concern in both the public and public health authorities (Kovats *et al.* 2004; Martinez-Navarro *et al.* 2004). However, the impact of cold weather on health has received much less attention despite its relationship with higher mortality and morbidity (Gomez-Acebo *et al.* 2010).

Although some of the excess winter mortality can be explained in some instances in terms of epidemics such as influenza; there are many studies which have taken account of influenza and still demonstrate a strong relationship between increased mortality and cold temperatures (Goodman *et al.* 2011). In several temperate countries, associations

between daily outdoor temperature and mortality appear to have weakened in recent decades (Barnett 2007; Carson *et al.* 2006; Hajat *et al.* 2007; Lerchl 1998; Medina-Ramon and Schwartz 2007).

The mortality of current day is often derived from exposure to today's temperatures and temperatures on several previous days or weeks (Anderson and Bell 2009; Bi *et al.* 2008). The effects for cold weather have been estimated to increase after several days, persisting for approximately several weeks and can exhibit a direct and indirect impact on mortality from days to weeks showing that temperature variability is an important determinant of human health effects (Alberdi *et al.* 1998; Analitis *et al.* 2008; Anderson and Bell 2009; Barnett *et al.* 2012; Braga *et al.* 2002; Carder *et al.* 2005; Donaldson and Keatinge 1997; Goodman *et al.* 2004; Gouveia *et al.* 2003; Guo *et al.* 2011; Pattenden *et al.* 2003; Saez *et al.* 1995; The Eurowinter Group 1997; Yu *et al.* 2011). The distributed lag model has been applied to explore the delayed effects of temperature on mortality (Analitis *et al.* 2008; Baccini *et al.* 2008; Hajat *et al.* 2005). Previous studies have explored the lag effects of temperature on mortality (Alberdi *et al.* 1998; Analitis *et al.* 2008; Anderson and Bell 2009; Braga *et al.* 2002; Carder *et al.* 2005; Goldberg *et al.* 2011; Goodman *et al.* 2004; Huynen *et al.* 2001; Lin *et al.* 2011).

In both the United States and Europe, an increase in the number of deaths has been recorded after winter cold spells and summer heatwaves (Larsen 1990). The immediate associations of cold on mortality rates have been reported in several studies (Alberdi *et al.* 1998; Ballester *et al.* 1997; Kunst *et al.* 1993; Larsen 1990; The Eurowinter Group 1997). In the Netherlands, annual cold-related mortality was higher than heat-related mortality (Keatinge 2002). Most of the excess mortality in winter was reportedly due to respiratory, cardiac and cerebrovascular disease (Hajat and Haines 2002). The associations on respiratory, cardiovascular and cerebrovascular diseases of cold temperatures has been reported to occur over prolonged periods, in some cases up to a few weeks duration (Alberdi *et al.* 1998; Donaldson and Keatinge 1997). Lower mean temperatures in south-east England (including London) were associated with excess deaths from all causes, observing the maximum associations three days after the cold peak and lasting up to 40 days (Donaldson and Keatinge 1997). Although cold temperatures show greater effects than hot temperatures, other factors such as

respiratory epidemics, usually present during the winter time, make unclear the precise role of temperature on increased morbidity and mortality (Braga *et al.* 2002).

A large US study described the decrease in mortality risk as a temperature increase from the coldest days to certain threshold temperature, above which mortality risk increased with temperature (Curriero *et al.* 2002). A similar pattern has been seen in Europe (Baccini *et al.* 2008; Hajat and Haines 2002; Keatinge *et al.* 2000; Kunst *et al.* 1993), and in a number of lower and middle income countries (McMichael *et al.* 2008). Periods of extreme cold or heat have also been associated with mortality peaks (Huynen *et al.* 2001). A Chinese study showed that significant associations between cold temperatures and mortality (cold associations) appeared after three days and last for up to 10 days (Guo *et al.* 2011). A study in Thailand observed that cold temperature was significantly associated with the risk of all mortality types and age groups, except for respiratory mortality (Guo *et al.* 2012).

A study of temperature-related mortality for Dublin showed that cold temperatures were associated with increased all-cause mortality; and that the effects extended for 2 to 3 weeks, and were not just an immediate acute effect: these increases in mortality were observed in all age groups, with the biggest effects in the elderly (Goodman *et al.* 2004). These effects of temperature on mortality in Dublin were similar to reports from other European studies (Analitis *et al.* 2008; Goodman *et al.* 2004). A study in Scotland reported that each 1°C reduction in weekly average temperature in Scotland was associated with an approximately 1% increase in total mortality, which persisted for several weeks (Gemmell *et al.* 2000). Lower mean temperatures in the East of England have been associated with excess deaths from all causes (Donaldson and Keatinge 1997). A study in London reported that a 1°C decrease in temperature was associated with 3% increase in total deaths over the next 24 days in greater London (Keatinge and Donaldson 2001). Others have also reported strong associations between increased mortality and prolonged periods of cold weather in London (The Eurowinter Group 1997; Wilkinson *et al.* 2001).

A study in the United States (US) found that both high and low temperatures were associated with increased cardiovascular mortality in analysis of cardiovascular

mortality in eight US cities (Braga *et al.* 2002). It was reported that winter respiratory deaths peaked about 12 days after the cold spell (Keatinge 2002). The short-term associations of cold on mortality persisted for up to 23 days with no evidence of mortality displacement (Analitis *et al.* 2008). A large US study reported that cold-related mortality was most associated with the longer lag period (average of current day to 25 days preceding death) (Anderson and Bell 2009). A study in the US found no clear evidence for an extra association of cold waves of the general associations of cold temperatures, although they stress that cold temperatures still posed a significant health problem (Barnett *et al.* 2012). A study in Scotland observed that respiratory mortality persisted to 4 weeks preceding death (Gemmell *et al.* 2000).

Cold-related mortality was most associated with longer lags (average the current day to 25 days previous) (Anderson and Bell 2009). A study in Germany found that cold spells lead to excess mortality to a relatively small degree which lasted for weeks (Laschewski and Jendritzky 2002). A Japanese study reported that exposure to cold temperatures triggered cardiovascular deaths (Atsumi *et al.* 2013). However, a Spanish study did not detect a trend on the cold-related mortality trigger thresholds (Miron *et al.* 2012). They suggested that the trend towards a decline in the cold temperature-mortality associations has also been accompanied by the favourable trend in economic indicators during the study period including improvement of the Spanish health service (Miron *et al.* 2012).

A Russian study observed that the cold weather-mortality associations persisted up to 6 days preceding death (Revich and Shaposhnikov 2008). A Chinese study found that the cold associations persisted for 10 to 12 days (Yang *et al.* 2012). A Canadian study reported modest increased associations from 2 to 5 days in cold temperatures (Goldberg *et al.* 2011). However, although they applied a long distributed lag structure over a long study period, they suggested that the lack of pronounced cold associations may be the result of homes in the study population being well insulated (Goldberg *et al.* 2011). An Australian study observed that the cold associations persisted for 21 days preceding death (Yu *et al.* 2011). A US study finds similar prolonged associations (Braga *et al.* 2001). A study in Thailand observed that cold temperature was significantly associated with the risk of all mortality types and age groups, except for respiratory mortality (Guo *et al.* 2012). A study of 12 cities in the United States found that the cold associations persisted for several weeks (Braga *et al.* 2002). A Chinese study showed that significant

associations between cold temperatures and mortality (cold associations) appeared after three days last for up to 10 days (Guo *et al.* 2011).

1.4 Modelling approaches

There have been a number of studies, which have assessed the cold weather-mortality associations, and have been conducted across the world from temperate to tropical climates, varying in population type, study design, length of study, population sample size and length of lag structure (see Table 1). Studies have indicated that prolonged associations of exposure to cold temperatures may increase mortality and show that temperature variability is an important determinant of human health (Analitis *et al.* 2008; Barnett *et al.* 2012; Braga *et al.* 2002; Carder *et al.* 2005; Donaldson and Keatinge 1997; Guo *et al.* 2011; Saez *et al.* 1995; The Eurowinter Group 1997). Studies have also examined the effect modification of age and gender on the cold weather and mortality relationship (Barnett *et al.* 2012; Kysely *et al.* 2009; Medina-Ramon *et al.* 2006; Nielsen *et al.* 2011; O'Neill *et al.* 2003; Sheth *et al.* 1999; Yang *et al.* 2012).

The distributed lag model has been applied to explore the delayed effects of temperature on mortality (Analitis *et al.* 2008; Anderson and Bell 2009; Hajat *et al.* 2007).

Epidemiologic studies have explored the delayed effects of temperature on mortality over medium lag structures (up to 2 weeks) (Atsumi *et al.* 2013; Barnett *et al.* 2005; Hajat *et al.* 2007; McMichael *et al.* 2008; Rocklov *et al.* 2011); while long lag structures of up to 5 weeks have also been explored (Analitis *et al.* 2008; Anderson and Bell 2009; Barnett *et al.* 2012; Goldberg *et al.* 2011; Lin *et al.* 2011; Miron *et al.* 2012; Tian *et al.* 2012).

Fewer studies have considered a longer lag structure (longer than 5 weeks) (Donaldson and Keatinge 1997; Gemmell *et al.* 2000; Goodman *et al.* 2004). Studies have explored the lagged association of temperature on mortality, including longer lag structures and these studies have applied the Poisson generalised additive models and regression models to explore the temperature impact on mortality (Analitis *et al.* 2008; Anderson and Bell 2009; Armstrong 2006; Carder *et al.* 2005; Dominici *et al.* 2004; Goldberg *et al.* 2011; Goodman *et al.* 2004).

In addition to the distributed lag structures, the length of the study periods and the population sample size add to the strength of the studies. Many of the above studies have applied Poisson regression with short-medium or long lag structures to varying lengths of study periods and population sample sizes. However, few studies have applied a combination of long lag structures, a long study period and a large sample size (Anderson and Bell 2009) while others have used a longer lag structure and long study period but have not specified their population sample size (Carder *et al.* 2005; Carder *et al.* 2008; Goldberg *et al.* 2011; Huynen *et al.* 2001; Keatinge and Donaldson 2001; Lin *et al.* 2011). None of these studies applied the case-crossover approach.

Some studies have applied a combination of both Poisson regression and case-crossover approach to their studies (Guo *et al.* 2011; Guo *et al.* 2013; Tian *et al.* 2012). However, two of these studies applied short-medium distributed lag structures (Guo *et al.* 2013; Tian *et al.* 2012) while the other study used a long distributed lag structure (Guo *et al.* 2011). However, all of those studies applied a short study period while two studies did not specify their population sample size (Guo *et al.* 2011; Guo *et al.* 2013) while the other study used a small sample population (Tian *et al.* 2012).

The Poisson generalised additive model was widely used to explore the lagged association of temperature on mortality (Analitis *et al.* 2008; Anderson and Bell 2009; Armstrong 2006; Ballester *et al.* 1997; Dominici 2004; Goodman *et al.* 2004; Hajat *et al.* 2007; Rocklov *et al.* 2011). Poisson regression has the advantage of controlling for many potential confounders by design since same population is examined repeatedly under varying exposure conditions but with constant, or slowly varying, covariate patterns such as gender and racial make-up (Bateson and Schwartz 1999). Time trend and seasonal effects of exposure levels and counts of outcomes are potential confounders, and are typically controlled for by modelling (Bateson and Schwartz 1999).

Another approach to estimating the effects of cold temperature on mortality involves the use of the case-crossover by design and this has been used in recent studies assessing temperature and mortality (Guo *et al.* 2011; Wichmann *et al.* 2011; Yu *et al.* 2012). The case-crossover design controls for seasonal variation, time trends, and slowly time

varying confounders by design (Bateson and Schwartz 1999, 2001; Levy *et al.* 2001a). The case-crossover approach makes examination of effect modification more straightforward because it focuses on individual events rather than daily counts (Schwartz, 2004).

The studies, which have used the case-crossover design, have applied a short-medium lag structure and a short-medium study period (Atsumi *et al.* 2013; Gomez-Acebo *et al.* 2010; Hong *et al.* 2003; Medina-Ramon and Schwartz 2007; Wichmann *et al.* 2011; Wichmann *et al.* 2012) at the time of writing. There have been no studies which have applied the case-crossover design to explore the association of temperature on all-cause mortality: cardiovascular disease (CVD), ischaemic heart disease (IHD), myocardial infarction (MI), all respiratory disease (RD), chronic obstructive pulmonary disease (COPD), pneumonia and stroke mortality over a longer lag structure (5 weeks or more) and longer study period (24 years) in a temperate zone with a large population sample, including urban and rural communities across the whole of the island of Ireland, which included two different governmental jurisdictions.

A previous Irish study had examined the relationship between cold weather and mortality in one city over a period of 17 years using Poisson regression models (Goodman *et al.* 2004). However, this MPhil study expanded upon an earlier Irish study by Goodman *et al.* (2004) by applying a different modelling approach (case-crossover) over a longer and more recent study period to the whole of the island of Ireland with a large population sample, incorporating both urban and rural communities rather than one city. There have been no studies to date which have determined the effect modification of age and gender on the relationship between cold weather and mortality by case-crossover design over a longer lag structure and longer study period in a temperate zone under the influence of the Gulf Stream and the control of two different governmental jurisdictions and assessing the pneumonia, COPD and stroke mortality relationship. The present study sought to address this gap in the literature.

1.5 Aims of the study

Although there has been a general trend of rising average temperatures in Ireland over the past 30 years, the island has witnessed extreme cold weather events over the same

period (Met Eireann 2014a, 2014b; The United Kingdom Met Office 2014a, 2014b). Taking into consideration the differences in underlying population health, public policies targeted at preventing winter mortality, health care provision, and socioeconomic and demographic construct of the two Irish jurisdictions (Goodman *et al.* 2011; Healy and Clinch 2004; McAvoy 2007), the health impacts of cold weather could potentially differ. It is therefore important to understand the magnitude and geographic differences of the cold weather-health relationship on the island of Ireland in order to inform public policies aimed at improvement of population health, and targeting of vulnerable groups during periods of cold weather.

It is against this background that this thesis explores winter mortality on the island of Ireland, comparing the Republic of Ireland with Northern Ireland, and comparing the winter and summer periods and winter and cold periods. A clear message from the literature is that cold weather effects can act over quite a prolonged time period, and that it is not just one or two cold days that effect people. It seems that long periods of cold weather appear to weaken those who are susceptible; and that if the cold weather continues they may get progressively weaker and eventually die while if temperatures rise they may recover.

This study carried out a comparative, two jurisdictional, cross-border project which worked in collaboration with the Centre for Ageing Research and Development in Ireland, Dublin Institute of Technology and the Public Health Institute in Ireland. There were two aims of this Master of Philosophy (MPhil) project (within the overall study).

The first aim of the study was to explore the comparison of the differences between the summer and winter mortality rates and the differences within the winter and cold period mortality rates by age and gender between the Republic of Ireland and Northern Ireland.

The second aim of the study was to assess the distributed lag structure of cold temperature association on mortality during the cold period and winter months in the Republic of Ireland and Northern Ireland over a study period of 24 years, applying a case-crossover approach with longer distributed lag structure and study period than

most previous studies; and to assess for effect modification of the cold weather mortality relationships by age and gender.

2.0 METHODS AND MATERIALS

There were two aims to this study: the first aim involved a comparison of excess winter mortality rates between the two jurisdictions of the Republic of Ireland and Northern Ireland, and the mortality rates amongst the younger and older population groups in the winter months and cold period; the second aim involved an assessment of the cold weather-mortality associations in both jurisdictions and the effect modification of that relationship by age and gender. The methods, analysis and findings of this study were included in a chapter within an international report published by the Public Health Institute in Ireland as part of a collaboration between Brunel University, Dublin Institute of Technology and the Centre for Ageing Research and Development in Ireland and in an academic paper in the *Environmental Health Journal*, of which the author of this study was a co-author in both publications (see Appendices 1 and 2).

2.1 Mortality counts

Individual daily deaths for ages ≥ 18 years were obtained from the Irish Central Statistics Office for data in the Republic of Ireland and Northern Ireland Social Research Agency for data in NI for the period of January 1st 1984 and December 31st 2007. The international Classification of Disease-9 (ICD-9) codes were used up to 2006, and ICD-10 codes from 2007. Non-accidental deaths were used for this study (ICD-9 codes 001-799/ICD-10 codes A00-R99), further categorised to primary cause-specific mortality for CVD (390-429; I01-I52), IHD (410-414, 429.2; I20-I52), MI (410; I21-I22), RD (460-519; J0-J99), pneumonia (480-486; J12-J18), COPD (490-492, 494-496; J40-J44, J47), and stroke (430-438; I60-I69). The above coding was used in both stages of this study and in the two co-authored publications enclosed in Appendices 1 and 2. The mortality parameters also included county codes and social/occupational class as well as place of birth in the Republic of Ireland and comparable parameters were used in Northern Ireland. The mortality data was read into SAS 9.1/9.2 to create SAS datasets which were checked for accuracy before analysis.

2.2 Weather data

The weather data for the study period (1984-2007) were obtained from Met Eireann, the Irish Meteorological Service for the Republic of Ireland; and the United Kingdom Met Office for Northern Ireland and this weather data was also used in the analysis for

the second stage of this research, the results of which were included in the publication attached in Appendix 2.

Ten weather stations were selected for the Republic of Ireland and these included Birr, Clones, Casement Aerodrome, Cork, Dublin, Kilkenny, Malin Head, Rosslare, Shannon and Valentia; and the four weather stations, which were selected for Northern Ireland included Armagh, Aldergrove, Ballywatticock, and Banagher. The parameters of the weather data included maximum, minimum, and mean daily temperatures, relative humidity, wind speed and direction, and air pressure for the Republic of Ireland and maximum, minimum, and mean daily temperatures and relative humidity for Northern Ireland. There was inconsistent data available for air pressure and wind speed and direction for all the weather stations in Northern Ireland. The weather data was checked for accuracy and descriptive analysis was performed (see Table 15).

The county codes obtained from the mortality data were assigned to the nearest weather station based on their geographical proximity to them. The weather and mortality data for each jurisdiction were merged by their county codes and this was used to generate hazard datasets for running models in the application of the time-stratified case-crossover approach used in this study and highlighted in the co-authored paper in Appendix 2.

2.3 Mortality rates

The census population data for the years 1986, 1991, 1996, 2002, 2006 was accessed from the Central Statistics Office in Ireland with regards to the Republic of Ireland, and from the Northern Ireland Research and Statistics Agency for Northern Ireland. The census was undertaken every 5 years in the Republic of Ireland and every 10 years in Northern Ireland, in line with the rest of the United Kingdom. In order to compare the mortality rates in both jurisdictions, an assumption was made that there was an uniform increase in population during the intervening census years in Northern Ireland and the non-census year population estimated by subtracting the population of the lower census year from the following census year (for example, population in 1981 subtracted from the population in 1991, etc.) and dividing by the number of intervening years to estimate the population increase. This was multiplied by the number of years from the

lower census year (for example, 1981 and the year required (for example, 1986) for comparison and added to the lower census year. This was repeated for the remaining comparative years of 1996, 2002, and 2006. The mortality rates were calculated as follows: (mortality/population) x 100,000 to give the mortality rates per 100,000. This study analysed the mortality data by age stratification (18-64 years old, 65-74 years old, 75-84 years old, and 85 years and older). Initially, all-cause mortality, CVD, RD and stroke were selected as these particular causes of death had been shown in other studies as demonstrating strong seasonal trends, such as excess winter mortality (Goodman *et al.* 2011). This study also analysed the mortality data for IHD, MI, COPD and pneumonia for age and gender and compared mortality rates of all year (annual), summer/winter mortality rates, winter mortality rates, mortality rates during the cold period (October – March) and by age and gender between each jurisdiction.

2.4 The concept of the case-crossover approach

The second stage of this study involved the assessment of the cold weather-mortality association between the two jurisdictions and by effect modification of that relationship with the application of the case-crossover approach. The most common technique for modelling the co-variation of environmental exposures and counts of health events over time has been Poisson regression analysis (Schwartz 1993; Schwartz *et al.* 1996). An approach that examines associations over time rather than over space is attractive because many potential covariates are controlled by design, rather than by regression modelling (Neas *et al.* 1999). Time invariant characteristics such as sex and race are not potential confounders because the same population is examined repeatedly under varying exposure conditions (Neas *et al.* 1999). Covariates that have secular trends or vary seasonally may be weakly correlated with environmental exposures, but the potential for these covariates to confound the short-term health effects of temperature may be controlled by modelling time trends and season. More sophisticated analytical techniques have been introduced for trend and seasonal adjustment, culminating in the introduction of generalised additive models (Schwartz 1993). An issue in the Poisson regression analyses has been the lack of a full enumeration and characterisation of the population at risk (Neas *et al.* 1999). To omit the offset term from the Poisson regression model, the investigator must assume that the population at risk is very large relative to the daily number of events and that the composition and size of the

population at risk does not co-vary with the exposure of interest (Neas *et al.* 1999). The case-crossover design avoids both problems by restructuring the analysis (Maclure 1991).

The case-crossover study design has been applied in a large number of epidemiologic studies, and its use is common in studies of the health effects of environmental exposure (Wang *et al.* 2011). It has also been reported (Wang *et al.* 2011) that case-crossover methods have been applied to studies in a number of different substantive areas, including cardiovascular disease (Baylin *et al.* 2007; Levy *et al.* 2001b; Mittleman 2005; Muller *et al.* 1996), and environmental epidemiology (Ng *et al.* 2008; O'Neill *et al.* 2003; Tsai *et al.* 2003). The case-crossover design is a form of the matched case-control design, making it influentially appealing for epidemiologic studies (Maclure and Mittleman 2000; Neas *et al.* 1999).

The case-crossover design is used to evaluate associations between short-term exposure to risk factor and the onset of adverse health effects (Janes *et al.* 2005; Maclure 1991). In one common implementation of this design, each subject's exposure before a case-defining event (case period) is compared with his or her own exposure experience during one or more control periods in which the subject did not become a case (Wang *et al.* 2011). The study population consists solely of cases who serve as their own controls in the analysis (Lu *et al.* 2008). Hence, the control periods are chosen from each case's history as a substitute for the selection of an external comparison group (Lu *et al.* 2008). The use of matched, within-subject comparison provides effective control of confounding by measured or unmeasured subject characteristics that are stable over time; although confounding by time-varying characteristics or exposures is still possible (Janes *et al.* 2005; Maclure 1991). The implementation of the case-crossover design is analogous to a matched case-control study, and the odds ratio estimated with conditional logistic regression – or equivalently the stratified Cox proportional hazards model- is typically used as the measure of association (Wang *et al.* 2011).

The application of the case-crossover method involves assigning the same exposure history to all persons experiencing the event of interest on a given day (Wang *et al.* 2011). In theory, case-crossover analyses should treat each event as a separate stratum

in the analysis; however, in settings where exposure is shared, it is often convenient to condition the analyses on calendar day rather than the individual (Wang *et al.* 2011). An advantage of conditioning on day allows data to be aggregated into fewer strata and so analytic data sets are small and computation time is reduced substantially (Wang *et al.* 2011). It has been shown that when an appropriate control selection strategy is used, conditional logistic regression stratified on the individual subjects yields unbiased estimates of the relative risk (Levy *et al.* 2001a; Lumley and Levy 2000).

The set of event and referent periods established for each case's exposure history is the reference window (Lu *et al.* 2008). The self-matching approach allows for control of potential confounding by time-sized factors – an often-cited benefit of the design (Lu *et al.* 2008). Various sampling strategies are used to select reference periods to estimate the associations of air pollution and/or temperature exposures on a health outcome of interest (Lu *et al.* 2008). Various referent sampling strategies have been employed to control for confounding by time-varying factors (Bateson and Schwartz 1999; Checkoway *et al.* 2000; Navidi 1998; Navidi and Weinhandl 2002). The goal is to limit the referent selection interval to short-term periods that restrict time-varying factors (such as seasonal characteristics of health and exposure, day-of-the-week effects, of other long term trends in air pollution or weather patterns) to be essentially constant within the reference window (Bateson and Schwartz 2001; Janes *et al.* 2005a; Lumley and Levy 2000).

Referent sampling schemes specific to environmental epidemiology use reference periods both before and after the time of the event (bidirectional referent sampling) as a method to reduce bias due to temporal trends in exposure and outcome variables (Greenland 1996; Navidi 1998). Due to concerns about potential overlap bias in the symmetric bidirectional design, the time-stratified design is considered the most generally valid approach for case-crossover studies of acute air pollution and temperature effects (Mittleman 2005). In the time-stratified design, the follow-up period is partitioned a priori into disjoint reference windows (Lumley and Levy 2000).

The most common analytic approach employs conditional logistic regression to compare the exposure at the time of the event to the exposure for the remaining control

periods within this pre-specified window (Lu *et al.* 2008). The time-stratified design method maintains desirable multivariable modelling properties by restricting reference windows that minimise confounding by seasonal and short-term patterns in exposure measures (Lu *et al.* 2008). A typical strategy is to constrain the reference-period selection to exposures matched by day of the week during the same calendar month as the case event (Levy *et al.* 2001a; Lumley and Levy 2000). This allows for asymmetric reference windows in which the case event is not centrally located by design (Lu *et al.* 2008). It has been shown that the case-crossover method using conditional logistic regression is a special case of a time-series log-linear model when there are common exposures across subjects in each time period (Lu and Zeger 2007). This is the case in temperature and mortality studies.

It has been advocated that time-stratified referent selection be used, because this design, avoids overlap bias and time trend bias (Janes *et al.* 2005). The stratification can be tailored to match on the most important time-dependent confounders; stratifying on year and month (as well as one or more of the following variables – day of week, temperature, measurement time, and weather metrics such as relative humidity and air pressure) is adequate for most studies (Janes *et al.* 2005). Although the semi-symmetric bidirectional design can also achieve these goals, this design requires modification of the traditional conditional logistic regression analysis and will be less efficient than a time-stratified design because fewer referents are used (Janes *et al.* 2005).

The case-crossover design has been viewed as an attractive alternative to time-series model for studying the acute effects of transient exposures (Lu *et al.* 2008). The current understanding is that the case-crossover approach controls for potential confounding by design, while time-series methods control for this source of bias by modelling (Bateson and Schwartz 2001; Janes *et al.* 2005; Mittleman 2005). Important modelling assumptions must be recognised and addressed during data collection and analysis using the case-crossover approach (Lu *et al.* 2008).

Both Poisson regression and case-crossover methods control for potential confounding in their respective regression models; however, different assumptions are made about the nuisance function (S_t) that represents potential temporal confounding influences (Lu

et al. 2008). It was reported that the equivalence of case-crossover and time-series methods allows one to use standard log-linear model diagnostic tools to check models inherent in case-crossover analysis (Lu *et al.* 2008; McCullagh and Nelder 1989).

The equivalence of time-series and case-crossover estimating equations means that the two methods produce the same estimator of the relative risk (Lu *et al.* 2008). Most case-crossover analysis relies on conditional logistic regression and assume that all subjects are independent (Lu *et al.* 2008). For common exposures shared by subjects, such as in ambient air pollution studies and temperature studies, this is equivalent to assuming that the number of events on day t , follows a Poisson distribution (Lu and Zeger 2007). Hence, the case-crossover approach is equivalent to log-linear time-series model without over dispersion, and it uses the Poisson variance to calculate the standard error (SE) of the log relative risk estimates (Agresti 2002). The time-stratified case-crossover design is equivalent to Poisson regression with indicator variables for strata (Levy *et al.* 2001a). The smooth function of time (S_t) is assumed to be a step function with different levels of total population baseline risk for each stratum (Lu and Zeger 2007). The symmetric bidirectional case-crossover design is equivalent to Poisson regression using a locally weighted running-mean smoother to estimate S_t .

2.4.1 Advantages of the case-crossover design approach

The case-crossover design is attractive because it only involves cases and each case is compared to himself/herself, thereby controlling for time-invariant personal factors (Lu and Zeger 2007). The current understanding is that case-crossover methods control for potential confounding “by design” while time-series methods control by modelling (Bateson and Schwartz 2001; Janes *et al.* 2005; Zanobetti and Schwartz 2005). An often-claimed rationale for the use of the case-crossover design is that it provides self-matched data both case and control periods and removes confounding by time-sized characteristics (Lu *et al.* 2008; Mittleman 2005; Redelmeier and Tibshirani 1997). Another claimed advantage is that it controls time-varying confounders such as seasonal and day of the week (dow) factors by design through short-interval reference-window specification; hence the conditional logistic regression model includes fewer terms than time-series models (Fung *et al.* 2003). The case-crossover conditional logistic regression model is equivalent to a particular time-series log-linear model

without over-dispersion (Lu and Zeger 2007).

Other strengths of the case-crossover design are that it does not require a control sample (and hence avoids bias associated with improper control selection); it makes effect modification assessment relatively simple; it controls for fixed confounders (Janes *et al.* 2005a). Another cited advantage of the case-crossover design is that more extensive personal information may be used in the analysis; for example, subject-specific characteristics and time-activity patterns that influence individual exposures or the time of case periods (Sheppard *et al.* 2001; Symons *et al.* 2006). The use of individual-level measures in a case-crossover analysis permits the researcher to estimate directly the effect of personal exposures, and to assess effect modification of exposure by individual attributes (Lu *et al.* 2008).

The time-stratified design is not subject to bias resulting from time trend because there is no pattern in the placement of referents relative to the index time: the design can control for season and day of the week (dow) by restricting referents to the same day of the week, month, and year as the index day (Janes *et al.* 2005a). Referents should be matched on the most dominant time-varying confounders and should be sampled bi-directionally (Janes *et al.* 2005a). Sampling referents too close to the index day will result in a loss of power as a result of auto-correlation in the exposure series (Janes *et al.* 2005a).

If there still remains a choice as to the number of referents at this point, larger number of referents will increase efficiency: the analysis should condition on the fixed exposure series (Janes *et al.* 2005a). The main difference between time-series regression method and analysis of a case-crossover design using conditional regression is that the former requires modelling for confounders (Janes *et al.* 2005). Within conditional logistic regression analysis in the case-crossover design, the confounding effects of all matching variables are controlled by design (Janes *et al.* 2005).

2.4.2 *Limitation of the case-crossover design approach*

Methods for addressing time-varying risk factors in case-crossover analyses have relied on the assumption that St , is constant within the reference window (Lu *et al.* 2008).

When this assumption is not satisfied, estimates from case-crossover models can also be biased, just as in any model when the predictors are incorrectly specified (Lu *et al.* 2008).

2.5 Method design and statistical analyses

This study applied a time-stratified case-crossover approach to assess the associations between cold weather and mortality in each of the two governmental jurisdictions on the island of Ireland (Republic of Ireland and Northern Ireland) and to assess for effect modification of the cold weather-mortality relationship by age stratification and gender and this approach was used in the co-authored paper (see Appendix 2).

As discussed earlier, the case-crossover design has been originally developed and used in air pollution's studies, and had been extensively described elsewhere (Bateson and Schwartz 2001; Levy *et al.* 2001a; Maclure 1991). The case-crossover design was developed as a variant of the case control design to study the effects of transient exposures on emergency events, comparing each person's exposure at the time of the case defining event or death (case time) with that person's exposure in other times (control times) (Maclure 1991).

A time-stratified approach was applied in this design to select the control days with the day of death chosen as the case day, and controls chosen as all other days, the same day of the week, in the same month and year as the case day, leaving two days between each control to eliminate any serial correlation (Bateson and Schwartz 1999, 2001; Lee *et al.* 2000; Levy *et al.* 2001a). Schwartz *et al.* (2003) showed that monthly strata had been used to produce unbiased estimates of effect sizes and coverage probabilities even in the presence of strong seasonal confounding (Schwartz *et al.* 2003). Conditional logistic regression was applied to matched pairs to compare different characteristics (Maclure 1991). An added advantage of this design is that, if control days are chosen close in time to the day of death, there is no confounding by slowly varying personal characteristics, and even very strong confounding by season and time trend can be removed (Bateson and Schwartz 1999; Lee *et al.* 2000; Lumley and Levy 2000).

The time-stratified case-crossover approach used in this study adjusted for the function

of time (St). This function approximately controls for time-varying confounders and time trends if there was no over-dispersion present in the data (Janes *et al.* 2005; Lu *et al.* 2008). The weather-mortality data was tested prior to choosing the modelling approach and no important over-dispersion was found in the data in both jurisdictions; therefore, the case-crossover approach was considered to be the most appropriate for estimating the cold weather-mortality relationship in this study (Zeka *et al.* 2014). The case-crossover using conditional logistic regression is a special case of time-series analysis (Lu and Zeger 2007). This equivalence provides computational convenience and permits model checking for the case-crossover design using log-linear model diagnostics (Lu *et al.* 2008)

2.5.1 *Definition of seasons*

The data were analysed for the winter season (December-February) and an extended cold period (October-March), with separate analyses conducted for the other months in the extended cold period; that is, Oct, Nov and March, commonly referred to as the cold months in order to investigate whether the observed cold weather-mortality associations were just confined to the winter months. This study observed cold-weather related mortality increases during the extended cold period, including the cold months. The associations in the cold months were weaker and less persistent than the cold period and winter months and so only the results for the cold period and winter months are presented in the next chapter. The definition of seasons, which was used in this study, was included in the published paper (see Appendix 2).

2.5.2 *Temperature metrics*

Different temperature definitions have been used in literature with no uniform criteria used to identify the best cold weather exposure metric (Barnett *et al.* 2012; Yu *et al.* 2011a). Some uncertainty remained as to which temperature indicator was the most suitable for analysing the impact of temperature on the various age groups and mortality categories (Yu *et al.* 2011a). This study tested daily maximum, daily mean and daily minimum temperatures as the exposure metrics in the models. There was an assumption that there would be little relief from the cold during the day (maximum temperature) whereas at night people's housing would provide protection from the effects of exposure to the cold (minimum temperature). In order to assess the influence

of temperature variability, such as sudden drops in temperature, the associations with the temperature differences between the daily maximum and daily minimum temperatures, the daily maximum and daily mean temperature, and weekly mean maximum and weekly mean minimum temperature were tested and examined as independent variables in the models (see Tables 6-9) (Zeka *et al.* 2014). The strongest mortality associations were observed with the daily mean and daily maximum temperatures in both jurisdictions, with only slight differences between them; these were slightly greater than those observed for minimum temperature, and so the daily maximum temperature was selected as an exposure metric. A previous study found that all temperature measured (mean, minimum, maximum, apparent) have a similar ability to predict mortality (Barnett and Astrom 2012). This study found that there were no important associations with regards to these definitions of temperature (Zeka *et al.* 2014).

2.5.3 *Time periods*

So, although the case-crossover approach controls for time-varying confounders and time periods by design, in preliminary analyses, this study tested the cold weather-mortality relationships for different time periods defined by the presence of fuel policy for each jurisdictions (1989-1990; 1995/1996) (Zeka *et al.* 2014). The cold period was chosen to include the enactments of the policies. In these analyses, there were some differences observed over time, with the associations slightly diminishing in more recent years for both jurisdictions (see Tables 10-13) (Zeka *et al.* 2014). However it was acknowledged that the temporal separation in these preliminary analyses was quite crude, and did not take into account other immediate and gradual changes in public policies and health care in the two jurisdictions (Zeka *et al.* 2014). It was possible that the response of the populations in the two jurisdictions to the cold temperatures has changed over time (Zeka *et al.* 2014).

2.5.4 *Definition of exposure variables*

This study aimed to examine the risk of mortality in association with exposure to daily maximum temperatures on the same day of the event (lag0) initially up to 6 weeks prior to death (lag 1-42 days). Weekly means of daily temperatures were calculated for each of the 6 weeks, for lag 1-7, lag 8-14, lag 15-21, lag 22-28, lag 29-35 and lag 36-42 days.

The distributed lag models included all weekly lags, with lag0 included as an independent variable. This modelling approach was a way to estimate unbiased time trends of the exposure-response relationship by controlling for any confounding in the temperature-mortality associations in one lag structure by temperature-mortality associations in other lags (Lee *et al.* 2000). The models were tested with a finer definition of lag structures such as the means of lag 1-2, 3-5, 6-9, 10-14, 15-21, 22-28 and 29-35 days to examine acute, medium and longer term effects of temperatures. However, the application of weekly mean temperature lag structures in the models revealed more efficient and stable results with the overall results being similar, whether using finer or average lag structures. All models included ‘day of the week’ as an indicator variable, with Monday as the reference. Additional variables in the model included relative humidity and atmospheric pressure, both of which were averaged over 3 days: the day of death and two days prior. There were no important contributions of relative humidity and atmospheric pressure found in any other lag structures. The models were tested with six, five and four distributed mean weekly lag structures. There were no important associations that were observed between any mortality cause and temperature in week 6 prior to death (lag 36-42 days) in both jurisdictions. This study found that there were important associations observed with temperatures up to 35 days (lag 29-35 days) before death for the Republic of Ireland, and up to 28 days (lag 22-28 days) for Northern Ireland during the cold period and winter months and these lag structures were chosen for the models. The models with the lowest Akaike Information Criterion (AIC) produced the strongest associations between the exposure to cold temperature and increased mortality outcomes, thus indicating a better fitting model. Although the models tested the cold weather-mortality relationship throughout the whole year, during the cold period, during the cold months and during the winter months, only the results for the cold period and the winter months are presented (see chapter 3). The cold weather-mortality relationship was analysed by applying conditional logistic regression analysis through the use of the PROC PHREG function in SAS 9.1/9.2, SAS Institute Cary, NC. The above method was applied in the co-authored published paper (see Appendix 2).

2.5.5 *Cumulative mortality increase estimate calculation*

The estimate for important associations between daily mortality and lags of weekly

average of maximum temperature prior to death was used to calculate cumulative estimates of mortality increases by summing the coefficients and the cumulative estimates did not include the association of mortality with temperature on the same day (lag 0) (Zeka *et al.* 2014). This association was consistent with previous studies assessing the cold weather-mortality relationship (Analitis *et al.* 2008; Goodman *et al.* 2004), where lag 0 was positive and potentially suggestive of warm temperature associations (Zeka *et al.* 2014). The overall variance was computed using previously described algorithms (Schwartz 2000).

During the cold period in the Republic of Ireland, the cumulative estimate (change) was calculated for the lag of week 1-5 for all-cause mortality, and RD mortality; for the lag of week 1-4 for, CVD mortality, IHD mortality, MI mortality, COPD mortality, and pneumonia mortality; and for lag 1-3 for stroke mortality. In the winter months, the cumulative estimate calculation did not change from that used for the cold period except for COPD mortality and pneumonia mortality where their cumulative change was calculated for lag of week 1-5. In Northern Ireland, during the cold period, the cumulative estimates were calculated for the lag of week 1-4 for all-cause mortality and stroke mortality; for the lag of week 1-3 for CVD mortality, IHD mortality, MI mortality, RD mortality and pneumonia mortality; and for the lag of week 1-2 for COPD mortality. During the winter months in Northern Ireland, the cumulative estimates were calculated for the lags of week 1-4 for RD mortality, COPD mortality and pneumonia mortality; and the lag of week 1-3 for the remaining mortality groups. The above approach was applied in the co-authored published paper (see Appendix 2).

2.5.6 *Modifying variables*

As the case-crossover approach focuses on individual events rather than daily counts, it also makes examination of effect modification more straightforward (Schwartz 2004). The effect modification of the temperature mortality relationship was examined by stratifying the models by gender, and age in the following groups: 18-64 year olds, 65-74 year olds, and 75+ years old (Zeka *et al.* 2014). Statistically important differences between cumulative estimates of strata of a potential modifier were tested by calculating the 95% confidence interval (95% (CI) of this difference (Payton *et al.* 2003).

This study did not consider adjustment for air pollution; these data were inconsistent across the two jurisdictions for the study period. The current practice in epidemiologic studies of weather and health association is to automatically adjust for air pollution, if the information on this is available. However, in a recent article, Buckley et al, indicated that there is no known mechanism by which air pollution confounds the cold temperature and mortality (health) relationship (Buckley et al 2014). In support of this rationale, previous epidemiologic studies showed little or no influence of air pollution on the cold temperature-mortality relationship (Analitis *et al.* 2008; Anderson and Bell 2009; Barnett *et al.* 2012; Braga *et al.* 2002; Goldberg *et al.* 2011; Goodman *et al.* 2004; Guo *et al.* 2012). This evidence emphasizes the robustness of these study findings, which are very important from a public policy perspective. The above approach was applied in the co-authored published paper (see Appendix 2).

Results are presented as percentage (%) change in mortality per 1°C decrease in weekly average of daily maximum temperature.

2.5.7 Ethical approval

This study received ethical approval from The Central Statistics Office in Ireland and Brunel University Ethics Committee. This study involved working in collaboration with the Centre for Age Reduction in Ireland, the Dublin Institute of Technology, and the Public Health Institute in Ireland.

3.0 RESULTS

3.1 Mortality counts

This study reported that there were 709,110 non-accidental deaths in the Republic of Ireland and 347,936 in Northern Ireland over the 24 years of the study data. Of these deaths during the year over the study period in the Republic of Ireland 33% of deaths were from cardiovascular disease (CVD), 25% from ischaemic heart disease (IHD), 17% from myocardial infarction (MI), 15% from all respiratory diseases (RD), 6% from chronic obstructive pulmonary disease (COPD), 7% from pneumonia and 9% from stroke. Northern Ireland showed a similar distribution with small variations; 31% of the deaths were from CVD, 23% were from IHD, 20% from MI, 17% from RD, 4% were from COPD, 10% from pneumonia and 11% from stroke. When this study stratified the deaths into the cold period (October – March), it was found that there were 381,099 non-accidental deaths in the cold period, which accounted for 54% of the deaths in the study data. The distribution of deaths during the cold period was comparable to the distribution throughout the year in the Republic of Ireland. In Northern Ireland, non-accidental deaths in the cold period accounted for 186,083, which was 53% of the deaths in the study data. The distribution of deaths in the cold period was comparable to the distribution for the whole year over the study period in Northern Ireland. More males died from non-accidental deaths, CVD, IHD, MI, RD and COPD while more females died from pneumonia and stroke in the Republic of Ireland. There was a similar trend reflected in Northern Ireland with the exception of RD where more females died than males in that cause-specific mortality group. This study observed that more males died amongst the 18-74 year olds while female deaths were greater in the 75+ year old age group with more than half of the deaths occurring in the 75+ year olds in both jurisdictions. Some of the above results have been presented in the co-authored publication in Appendix 2.

3.2 Mortality Rates

3.2.1 Annual mortality rates

There was a downwards trend in the annual mortality rates (all ages) for all-cause mortality in both jurisdictions across the study period (1986-2006) with an approximate overall decline of 20-25% (see Figure 1a). The annual mortality rates for all-cause mortality were higher in Northern Ireland than in the Republic of Ireland throughout the

study period and the Republic of Ireland experienced a sharper decline. Mortality from CVD also showed a downwards trend in both jurisdictions (see Figure 1b). The CVD mortality rate was higher in Northern Ireland than in the Republic of Ireland with a convergence of the rates in the middle of the study period. The rate of decline in CVD mortality was more constant in Northern Ireland although the rates of decline were comparable between the two jurisdictions. CVD mortality rates decreased by approximately 50% and 45% over the study period in the Republic of Ireland and Northern Ireland respectively. The annual mortality rates for IHD showed an overall downwards trend in both jurisdictions (see Figure 1c). The annual IHD mortality rates were higher in Northern Ireland compared to the Republic of Ireland. However, there was a reversal of this trend in the middle of the study period where the mortality rates were higher in the Republic of Ireland. The annual IHD mortality rates showed similar patterns to the CVD mortality rates, with similar overall rates of decline in both jurisdictions. Figure 1d showed the annual mortality rates (all ages) for MI in the Republic of Ireland and Northern Ireland, 1986-2006. The MI mortality rates showed an overall downwards trend in both jurisdictions, with an overall decline of approximately 67% and 60% in the Republic of Ireland and Northern Ireland respectively. The mortality rates for MI were higher in Northern Ireland than in the Republic of Ireland.

The annual mortality rates (all ages) for RD showed an overall downwards trend with a decline of approximately 30% at the end of the study period in both jurisdictions (see Figure 2a). The RD mortality rates were higher in Northern Ireland than in the Republic of Ireland; although in the year 2002, this pattern was reversed with the rates higher in the Republic of Ireland. In Northern Ireland, there was little change in the RD mortality rates until the year 1996 when there was a sharp drop. The annual mortality rates (all ages) for COPD showed an overall downwards trend in the Republic of Ireland while there was an increase in the COPD mortality rates in Northern Ireland throughout the study period (see Figure 2b). The COPD mortality rates were higher in the Republic of Ireland until the end of the study when the mortality rates were higher in Northern Ireland. There was a decrease in the annual COPD mortality rates of approximately 45% in the Republic of Ireland and an increase of 30% in Northern Ireland. The annual

mortality rates for pneumonia (all ages) showed an overall decline over the study period in both jurisdictions with the sharpest decline observed in Northern Ireland (see Figure 2c). Pneumonia mortality rates were higher in Northern Ireland than in the Republic of Ireland with a convergence of the rates towards the latter stages of the study. The annual pneumonia mortality rates declined by approximately 55% for Northern Ireland and 25% for the Republic of Ireland. Northern Ireland observed the sharpest decline in its pneumonia annual mortality rates between the years 1996 and 2002. The annual mortality rates for stroke (all ages) showed an overall downwards trend in both jurisdictions, with a decline of approximately 40-55% over the study period (see Figure 2d). The stroke mortality rates were higher in Northern Ireland compared with the Republic of Ireland.

3.2.2 Summer and winter mortality rates

Figure 3a showed the summer and winter mortality rates for all-cause mortality amongst the male population. Winter mortality was much greater than the summer mortality in both jurisdictions. Northern Ireland presented higher summer and winter mortality rates with the exception of the years 1996/1997 when this trend was reversed with the Republic of Ireland presenting higher mortality rates. Summer and winter mortality for the female population increased during the first half of the study period before declining during the remainder (see Figure 3b). Winter mortality was higher than summer mortality with Northern Ireland presenting higher summer and winter mortality rates compared to the Republic of Ireland.

The winter CVD mortality rates in the male population were higher than the summer mortality rates in both jurisdictions; with both the summer and winter mortality rates higher overall in Northern Ireland compared to the Republic of Ireland (see Figure 4a). There was some convergence of the CVD mortality rates by the end of the study. There was an overall downwards trend in both the summer and winter CVD mortality rates in the female population in both jurisdictions with the winter mortality rates being higher than the summer rates (see Figure 4b). The mortality rates were higher in Northern Ireland compared with the Republic of Ireland, with some convergence of rates by the end of the study.

The winter IHD mortality rates were higher than the summer rates in both jurisdictions. The summer and winter IHD mortality rates for the male population showed an overall downwards trend with the winter mortality rates being higher than the summer mortality rates in both jurisdictions (see Figure 5a), although there was some convergence of the summer and winter mortality rates in Northern Ireland. In the female population, the summer and winter IHD mortality rates showed an overall downwards trend in both jurisdictions (see Figure 5b). The winter IHD mortality rates were higher than the summer rates in both jurisdictions and there was some convergence of the rates in both jurisdictions by the end of the study. Both the summer and winter IHD mortality rates were higher in the male population than the female population in both jurisdictions (see Figures 5a-b). The difference between the summer and winter mortality rates decreased over the study period.

In the male population, the summer and winter MI mortality rates showed an overall downwards trend across the study period in both jurisdictions (see Figure 6a). The winter MI mortality rates were higher than the summer mortality rates in both jurisdictions while both the summer and winter mortality rates were higher in Northern Ireland than in the Republic of Ireland. The differential between the summer and winter MI mortality rates decreased over the study period with a convergence of the rates in both jurisdictions by the end of study. The summer and winter mortality rates for MI in the female population declined over the study period in both jurisdictions; the winter mortality rates were higher than the summer mortality rates in both jurisdictions (see Figure 6b). Northern Ireland showed higher summer and winter mortality rates than Republic of Ireland. The differential between the summer and winter mortality rates in the female population declined over the study period with a convergence of the rates by the end of the study. Both the summer and winter MI mortality rates were higher in the male population than the female population (see Figures 6a-b).

Although there was an overall downwards trend in the summer and winter RD mortality rates in the male population in both jurisdictions, this study observed that the winter RD mortality rates, in particular, had increased during the first half of the study before declining sharply in the second part of the study period (see Figure 7a). The winter RD mortality rates were approximately 35-40% higher than the summer mortality rates in

Northern Ireland and the Republic of Ireland at the start of the study; this differential declined over the study period to approximately 20-25% by the end of it in Northern Ireland and the Republic of Ireland. The summer and winter RD mortality rates were higher in Northern Ireland than in the Republic of Ireland. This study showed that there was a similar pattern in the female population; however the overall summer and winter mortality rates remained relatively unchanged by the end of the study in both jurisdictions (see Figure 7b). Both the summer and winter RD mortality rates were higher in Northern Ireland than in the Republic of Ireland. Although the winter RD mortality rates were higher in males than females for both jurisdictions at the start of the study; it was observed that the winter mortality rates were higher in females than males by the end of the study in Northern Ireland with comparable rates between both populations in Republic of Ireland (see Figures 7a-b). The study observed that the summer RD mortality rates were higher in the male population at the start of the study in both jurisdictions with a convergence of the rates between both populations by the end of the study period (see Figures 7a-b).

Comparable patterns and trends in the summer/winter pneumonia mortality rates were observed in both the male and female populations in both jurisdictions (see Figure 8a-b). Although the winter pneumonia mortality rates for the male population were approximately 30% higher than the summer rates in both jurisdictions at the start of the study, both rates converged by the end of the study period in both jurisdictions. A similar trend was observed for the female population although there was less convergence of the differential between the summer and winter mortality rates in Northern Ireland. The summer and winter pneumonia mortality rates were higher in Northern Ireland than Republic of Ireland (see Figs 8a-b).

In the male population, the study observed that the summer and winter COPD mortality rates declined over the study period in the Republic of Ireland; whilst in Northern Ireland, the summer mortality rate increased and the winter COPD mortality rates remained relative static across the study period (see Figure 9a). Although the summer and winter COPD mortality rates were higher in the Republic of Ireland at the start of the study, the winter mortality rates converged in both jurisdictions while the summer mortality rates were higher in Northern Ireland than the Republic of Ireland (see Figure

9a). The summer and winter mortality COPD mortality rates in the female population showed a small overall downwards trend in the Republic of Ireland although the winter mortality rates increased sharply at the beginning of the study (see Figure 9b). In Northern Ireland both the summer and winter COPD mortality rates increased over the study period. The difference between the summer and winter COPD mortality rates increased over the study period in the female population in Northern Ireland while it decreased in the Republic of Ireland (see Figure 9b). The summer and winter COPD mortality rates were higher in males than in females, a trend reflected in both jurisdictions (see Figures 9a-b).

The summer stroke mortality rates decreased over the study period in both jurisdictions; the winter mortality rates showed an overall downwards trend in the male population in both jurisdictions (see Figure 10a). The winter stroke mortality rates were higher than the summer mortality rates in both jurisdictions at the start of the study; however, by the end of the study, the summer and winter mortality rates were comparable in Northern Ireland, while the winter mortality rates remained higher than the summer rates in the Republic of Ireland (see Figure 10a). Both stroke mortality rates were higher in Northern Ireland than in the Republic of Ireland for the female population and there was a convergence of the rates by the end of the study (see Figure 10b). The summer and winter mortality rates were higher in females than males in both jurisdictions (see Figures 10a-b).

3.2.3 *Winter mortality rates*

The winter mortality rates for all-cause mortality remained stable until 1996/97 after which they declined sharply in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 11a). A similar pattern was observed for CVD mortality rates in the winter months in both jurisdictions with a convergence of the rates by the end of the study (see Figure 11b). The IHD mortality rates in winter showed an overall downwards trend with the rates very comparable between each jurisdiction (see Figure 11c). The winter MI mortality rates declined steadily in each jurisdiction with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 11d). The winter RD mortality rates increased initially before declining sharply from the middle of the study in both jurisdictions (see

Figure 12a). Northern Ireland presented higher winter RD mortality rates at the start of the study while the mortality rates were comparable between each jurisdiction by the end of the study. The COPD mortality rates increased initially in the Republic of Ireland before declining midway through the study period while the COPD mortality rates increased throughout the study period in Northern Ireland (see Figure 12b). The COPD mortality rates were higher in the Republic of Ireland at the start of the study while this pattern was reversed by the end of the study. The winter mortality rates for pneumonia increased initially before declining midway through the study period in both jurisdictions; with Northern Ireland presenting higher mortality rates than the Republic of Ireland although there was some convergence between the two jurisdictions by the end of the study (see Figure 12c). The winter mortality rates for stroke showed an overall downwards trends in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 12d).

3.2.4 Winter mortality rates by age stratification

The CVD mortality rates amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 13a). The winter CVD mortality rates amongst the 65-74 year olds showed an overall downwards trend in both jurisdictions; with the mortality rates higher in Northern Ireland than in the Republic of Ireland although there was some convergence of the mortality rates between the two jurisdictions by the end of the study period (see Figure 13b). There were decreases in the winter CVD mortality rates of approximately 63% and 68% in the Republic of Ireland and Northern Ireland respectively over the study period. Amongst the 75-84 year olds, the winter mortality rates showed an overall downwards trend, with a decline across the study period of approximately 54% and 49% in the Republic of Ireland and Northern Ireland respectively (see Figure 13c). The winter mortality rates for CVD were higher in the Republic of Ireland than in Northern Ireland for the 75-84 year olds. The 85+ year olds' winter mortality rates for CVD showed an overall downwards trend over the study period in both jurisdictions (see Figure 13d). The decline in the mortality rates was approximately 27% and 37% in the Republic of Ireland and Northern Ireland respectively with Northern Ireland presenting higher mortality rates than the Republic of Ireland. The winter mortality rates for CVD were highest in the 85+ year olds and

lowest amongst the 65-74 year olds in both jurisdictions (see Figures 13b-d), when considering the older population.

The IHD mortality rates amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 14a). The winter mortality rates amongst the 65-74 year olds showed a sharp decline throughout the study period (see Figure 14b). There was a decrease in the winter mortality rates of approximately 66% in both jurisdictions and the mortality rates were higher in Northern Ireland than Republic of Ireland over the study period. The winter IHD mortality rates amongst the 75-84 year olds also showed an overall downwards trend over the study period in both jurisdictions (see Figure 14c). There was a decrease of approximately 54% and 45% in the winter IHD mortality rates in the Republic of Ireland and Northern Ireland respectively, and the mortality rates were higher in the Republic of Ireland than Northern Ireland in this age group. The winter IHD mortality rates amongst the 85+ year olds showed an overall downwards trend despite a spike around the middle of the study period in both jurisdictions; with Northern Ireland presenting higher mortality rates than the Republic of Ireland. There was a decrease of approximately 12% and 24% in the winter IHD mortality rates in the Republic of Ireland and Northern Ireland respectively (see Figure 14d). The winter IHD mortality rates were higher amongst the 85+ year olds and lower in the 65-74 year olds (see Figures 14b-d), when considering the older population.

The winter mortality rates for MI amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 15a). The winter MI mortality rates amongst the 65-74 year olds declined over the study period in both jurisdictions, with Northern Ireland presenting higher winter MI mortality rates than the Republic of Ireland (see Figure 15b). The study found that the winter MI mortality rates decreased by approximately 81% and 74% in the Republic of Ireland and Northern Ireland respectively. The winter MI mortality rates amongst 75-84 year olds showed an overall downwards trend over the study period in both jurisdictions; with the Republic of Ireland presenting higher mortality rates than Northern Ireland at the start

of the study whilst the mortality rates in Northern Ireland were higher throughout the remainder of the study period (see Figure 15c). The study found that the winter MI mortality rates decreased by approximately 67% and 60% in the Republic of Ireland and Northern Ireland respectively. The winter MI mortality rates amongst the 85 + year olds showed an overall downwards trend despite a spike around the middle of the study period in both jurisdictions (see Figure 15d). The mortality rates were higher in the Republic of Ireland at the start and end of the study, while Northern Ireland experienced higher rates around the middle of the study period. This study found the winter MI mortality rates decreased by approximately 33% and 52% in the Republic of Ireland and Northern Ireland respectively. The winter mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds (see Figures 15b-d), when considering the older population.

The RD mortality rates amongst the 18-64 year olds were very low and, despite increasing at the start of the study, showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 16a). The RD mortality rates amongst the 65-74 year olds showed an overall downwards trend over the study period despite an increase around the middle of the study period in both jurisdictions (see Figure 16b). The winter RD mortality rates were higher in the Republic of Ireland at the start of the study and up to the middle of the study period while the rates were higher in Northern Ireland in the latter stages of the study. This study found that there was a decrease in the winter RD mortality rates of approximately 62% and 45% in the Republic of Ireland and Northern Ireland respectively. The winter RD mortality rates amongst the 75-84 year olds increased sharply during the first half of the study before decreasing even more sharply in the second half of the study period (see Figure 16c). The Republic of Ireland experienced higher winter RD mortality rates than Northern Ireland across the study period except for the years 1991/1992 when this pattern was reversed. This study observed that there was a decrease in the winter RD mortality rates amongst the 75-84 year olds of approximately 32% and 38% in the Republic of Ireland and Northern Ireland respectively. The winter RD mortality rates amongst the 85+ year olds increased during the first half of the study before declining in the second half of the study period (see Figure 16d). The winter RD mortality rates were higher in Northern Ireland than in the

Republic of Ireland. This study noted that the winter RD mortality rates decreased by approximately 27% and 39% in the Republic of Ireland and Northern Ireland respectively. The winter RD mortality rates were highest amongst the 85+ year olds and lowest in the 65-74 year olds in both jurisdictions (see Figures 16b-d) within the older population.

The COPD mortality rates amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with the Republic of Ireland presenting higher mortality rates at the start of the study while this pattern was reversed at the end of the study (see Figure 17a). The COPD mortality rates amongst the 65-74 year olds showed an overall downwards trend in both jurisdictions with a sharp decline in the Republic of Ireland between the years 1996/1997 and 2002/2003 (see Figure 17b). The winter COPD mortality rates were higher in the Republic of Ireland than Northern Ireland, until the latter stages of the study when this pattern was reversed with the rates higher in Northern Ireland than in Republic of Ireland. This study found that the winter COPD mortality rates decreased by approximately 63% and 14% in the Republic of Ireland and Northern Ireland respectively. The winter COPD mortality rates amongst the 75-84 year olds showed an overall downwards trend for the Republic of Ireland although there was an increase around the middle of the study, while there was an overall upwards trend for Northern Ireland (see Figure 17c). The winter COPD mortality rates were higher in the Republic of Ireland than in Northern Ireland although there was a convergence of those mortality rates in each jurisdiction by the end of the study period. There was a decrease in the winter COPD mortality rates of approximately 34% for the Republic of Ireland and an increase of 38% for Northern Ireland. There was an overall downward trend in the winter COPD mortality rates amongst the 85+ year olds in the Republic of Ireland and an overall upwards trend in the winter COPD mortality rates in Northern Ireland over the study period (see Figure 17d). The winter COPD mortality rates were higher in the Republic of Ireland than in Northern Ireland. There was some convergence of the mortality rates between the two jurisdictions over the study period. This study observed that there was a decrease in those mortality rates of 25% in the Republic of Ireland and an increase of approximately 22% in the COPD winter mortality rates in Northern Ireland. The winter COPD mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74

year olds (see Figures 17b-d).

The mortality rates for pneumonia were very low and showed an overall downwards trend in both jurisdictions, with Northern Ireland presenting higher rates than the Republic of Ireland (see Figure 18a). The winter mortality rates for pneumonia amongst the 65-74 year olds showed an overall downwards trend over the study period in both jurisdictions (see Figure 18b). The mortality rates were higher in Northern Ireland than the Republic of Ireland apart from the years 2002/2003 when the rates were higher in the Republic of Ireland. There was a convergence of the mortality rates by the end of the study. The study found that there was a decrease of approximately 74 and 72% in the Republic of Ireland and Northern Ireland respectively over the study period. The winter mortality rates for pneumonia amongst the 75-84 year olds increased initially before declining in the latter stages of the study (see Figure 18c). The mortality rates were higher overall in Northern Ireland than the Republic of Ireland with the exception of the reversal of trends in 2002/2003 when it was higher in the Republic of Ireland. There was a convergence of the mortality rates by the end of the study period. The study showed that there was a decrease of approximately 43% and 60% in the Republic of Ireland and Northern Ireland respectively by the end of the study period. The winter mortality rates for pneumonia amongst the 85+ year olds showed an overall downwards trend in both jurisdictions (see Figure 18d). There was an initial increase in the mortality rates during the first half of the study followed by a larger decline in the second half of the study period; this was more pronounced in Northern Ireland. The mortality rates were generally higher in Northern Ireland than the Republic of Ireland except for the years 2002/2003 which noticed a reversal of the trend with slightly higher rates in the Republic of Ireland. This study observed decreases of 38% and 55% in the winter pneumonia mortality rates in the Republic of Ireland and Northern Ireland respectively. The winter mortality rates for pneumonia were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds (see Figures 18b-d) within the older population.

Stroke mortality rates were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting slightly higher rates than the Republic of Ireland while there was a slight increase in the rates in Northern Ireland at the end of the

study (see Figure 19a). The winter mortality rates for stroke amongst the 65-74 year olds declined throughout the study period with Northern Ireland experiencing higher mortality rates than the Republic of Ireland (see Figure 19b). This study found that there were decreases of approximately 76% and 71% in the Republic of Ireland and Northern Ireland respectively over the study period. The winter mortality rates also showed an overall downwards trend amongst the 75-84 year olds with a convergence of the rates by the end of the study period (see Figure 19c). The mortality rates were higher in Northern Ireland compared to the Republic of Ireland throughout the study. This study noted that there were decreases of approximately 56% and 60% in the Republic of Ireland and Northern Ireland in their respective winter stroke mortality rates over the study period. The winter mortality rates for stroke amongst the 85+ year olds showed an overall downwards trend in both jurisdictions although there was an increase in the mortality rates in Northern Ireland around the middle of the study (see Figure 19d). The mortality rates from stroke were generally higher throughout the study in Northern Ireland compared with the Republic of Ireland although this trend was temporarily reversed in the years 1991/1992 when the winter stroke mortality rates were higher in the Republic of Ireland. This study found that the winter stroke mortality rates amongst the 85+ year olds decreased by approximately 50% and 46% over the study period in the Republic of Ireland and Northern Ireland respectively. This study observed that the winter stroke mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figures 19b-d) within the older population.

3.2.5 Cold period mortality rates by gender

The male all-cause mortality rates during the cold period showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates compared to the Republic of Ireland across the study period (see Figure 20a). This study found that the cold period all-cause mortality rates in the male population decreased by approximately 29% and 17% in the Republic of Ireland and Northern Ireland respectively. The CVD mortality rates for the male population showed an overall downwards trend in both jurisdictions; with Northern Ireland presenting overall higher mortality rates than the Republic of Ireland across the study period with the exception of the years 1996/97 when this trend was reversed with higher mortality rates

in the Republic of Ireland (see Figure 20b). This study found that there were decreases approximately 47% in the male CVD mortality rates during the cold period in both jurisdictions. The IHD mortality rates for the male population reflected a similar trend to the male CVD mortality rates in both jurisdictions (see Figures 20b-c). Northern Ireland presented higher mortality rates in the early and latter stages of the study while the Republic of Ireland reported higher rates around the middle of the study. This study observed that the cold period IHD mortality rates for the male population declined over the study by approximately 52% and 46 % in the Republic of Ireland and Northern Ireland respectively. The cold period MI mortality rates for the male population declined throughout the study; with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 20d). This study reported mortality rates for male MI mortality rates during the cold period decreased by approximately 69% and 61% in the Republic of Ireland and Northern Ireland respectively.

The male RD mortality rates for the cold period showed an overall downwards trend over the study period (see Figure 21a). Northern Ireland presented higher mortality rates during the first half of the study and at the end of the study while this pattern was reversed around the middle of study. This study observed that the cold period RD mortality rates for the male population decreased overall by approximately 31% in both jurisdictions. The COPD mortality rates for the male population reported an overall downwards trend in the Republic of Ireland while there was a small upwards trend in Northern Ireland (see Figure 21b). The Republic of Ireland presented higher mortality rates across the study period until the end of the study when this trend was reversed with Northern Ireland presenting the higher mortality rates. The COPD mortality rates for the male population decreased by approximately 47% in the Republic of Ireland and increased by 5% in Northern Ireland. The pneumonia mortality rates for the male population displayed comparable trends to COPD mortality rates (see Figures 21b-c). However, in the case of the pneumonia mortality rates, Northern Ireland presented higher rates over the study period with the exception of the years 2002/2003 when the trends were reversed with Republic of Ireland presenting higher mortality rates (see Figure 21c). The pneumonia mortality rates for the male population decreased by approximately 23% and 56% in the Republic of Ireland and Northern Ireland respectively. The stroke mortality rates for the male population declined across the

study in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 21d). Stroke mortality rates decreased by 52% and 39% in the Republic of Ireland and Northern Ireland respectively.

The all-cause mortality rates for the female population showed an overall downwards trend during the cold period in both jurisdictions with Northern Ireland presenting higher mortality rates throughout the study period (see Figure 22a). This study reported that the female all-cause mortality rates decreased by approximately 19% and 6% in the Republic of Ireland and Northern Ireland respectively. The cold period CVD mortality rates for the female population showed an overall downwards trend in both jurisdictions (see Figure 22b). Northern Ireland presented higher mortality rates over the study period although there was a convergence of the mortality rates in both jurisdictions by the end of the study. This study observed that the female CVD mortality rates during the cold period decreased by approximately 38% and 46% in the Republic of Ireland and Northern Ireland respectively over the study period. The female IHD mortality rates in the cold period followed a similar pattern to the female CVD mortality rates (see Figure 22b and 22c). Northern Ireland presented higher mortality rates in the female population over the study period although the rates were comparable between the two jurisdictions in the middle of the study. This study noticed that the female IHD mortality rates for IHD in the cold period had decreased by approximately 41% in both jurisdictions by the end of the study. The female MI mortality rates during the cold period declined across the study period in both jurisdictions with Northern Ireland presenting higher mortality rates over the whole of the study period (see Figure 22d). There was some convergence of the mortality rates by the end of the study. This study found that the female MI mortality rates during the cold period declined by approximately 60% and 61% in the Republic of Ireland and Northern Ireland over the study period.

The female RD mortality rates during the cold period increased during the first half of the study period before declining in the second half of the study; with Northern Ireland presenting higher mortality rates than the Republic of Ireland over the whole of the study period (see Figure 23a). There was a decrease of approximately 7% in the Republic of Ireland and an increase of 4% in Northern Ireland in the female RD

mortality rates during the cold period. The female COPD mortality rates showed no overall change over the study period in the Republic of Ireland while they increased steadily in Northern Ireland over the same period (see Figure 23b). The mortality rates for COPD mortality in females were higher in the Republic of Ireland until the middle of the study, after which the trend was reversed with Northern Ireland presenting higher mortality rates. This study reported that the female COPD mortality rates during the cold period did not show any overall change in the Republic of Ireland while in Northern Ireland the mortality rates increased significantly (163%) over the study period. The mortality rates for pneumonia in the female population reflected a similar trend displayed by the female RD mortality rates (see Figures 23a and 23c). Northern Ireland presented higher mortality rates over the whole of the study period. This study noted that the female pneumonia mortality rates decreased by approximately 20% and 29% in the Republic of Ireland and Northern Ireland respectively. The female stroke mortality rates during the cold period declined over the whole of the study in both jurisdictions (see Figure 23d). This study observed that the female stroke mortality rates during the cold period decreased by approximately 46% and 38% in the Republic of Ireland and Northern Ireland respectively with the mortality rates higher in Northern Ireland.

3.2.6 Cold period mortality rates by age stratification

The mortality rates for CVD amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates although the rates converged by the end of the study (see figure 24a). The CVD mortality rates amongst the 65-74 year olds declined throughout the study period in both jurisdictions (see Figure 24b). Northern Ireland presented higher mortality rates until the middle of the study period while the Republic of Ireland presented higher mortality rates in the latter stages of the study. This study reported that the cold period CVD mortality rates amongst the 65-74 year olds decreased by approximately 65% and 70% in the Republic of Ireland and Northern Ireland respectively. The CVD mortality rates amongst the 75-84 year olds declined across the study period in both jurisdictions; with the Republic of Ireland presenting higher mortality rates than Northern Ireland in this age group (see Figure 24c). This study found that there was a decrease in the cold period CVD mortality rates amongst the 75-

84 year olds of approximately 52% and 54% in the Republic of Ireland and Northern Ireland respectively. The CVD mortality rates amongst the 85+ year olds showed an overall downwards trend in both jurisdictions; with the Republic of Ireland presenting higher mortality rates than Northern Ireland over the study period (see Figure 24d). This study observed that the CVD mortality rates amongst the 85+ years olds decreased by approximately 28% and 34% in the Republic of Ireland and Northern Ireland respectively. The cold period CVD mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figures 24b-d) within the older population.

The mortality rates for IHD amongst the 18-64 year olds were very low and showed an overall downwards trends in both jurisdictions with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 25a). IHD mortality rates amongst the 65-74 year olds declined over the study period (see Figure 25b). Although Northern Ireland presented higher mortality rates at the start and in the latter stages of the study period, the Republic of Ireland presented higher mortality rates during the middle stages of the study. This study found that the cold period IHD mortality rates amongst the 65-74 year olds decreased by approximately 69% in both jurisdictions. The IHD mortality rates amongst the 75-84 year olds showed an overall downwards trend in both jurisdictions with the Republic of Ireland presenting higher mortality rates than Northern Ireland over the study period (see Figure 25c). This study reported that the IHD mortality rates amongst 75-84 year olds decreased over the study period by approximately 55% and 49% in the Republic of Ireland and Northern Ireland respectively. The IHD mortality rates amongst the 85+ year olds showed an overall downwards trend in both jurisdictions; again with the Republic of Ireland presenting higher mortality rates than Northern Ireland over the study period (see Figure 25d). This study observed that the cold period IHD mortality rates amongst the 85+ year olds decreased by approximately 16% and 23% in the Republic of Ireland and Northern Ireland respectively. The cold period IHD mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figure 25b-d) within the older population.

Mortality rates for MI amongst the 18-64 year olds were very low and showed an

overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates although the rates converged by the end of the study (see Figure 26a). The MI mortality rates for the 65-74 year olds declined over the study period in both jurisdictions; with Northern Ireland presenting the higher mortality rates than the Republic of Ireland during this time (see Figure 26b). This study found that the MI mortality rates amongst the 65-74 year olds decreased by approximately 81% and 77% in the Republic of Ireland and Northern Ireland respectively over the study period. The cold period MI mortality rates amongst the 75-84 year olds declined over the study period in both jurisdictions (see Figure 26c). Although the MI mortality rates were higher in Republic of Ireland at the start of the study, Northern Ireland presented higher mortality rates for the remainder of the study. This study reported that the cold period MI mortality rates amongst the 75-84 year olds decreased by approximately 67% and 62% in the Republic of Ireland and Northern Ireland respectively. The MI mortality rates amongst the 85+ year olds showed an overall downwards trend in both jurisdictions (see Figure 26d). The mortality rates varied between the two jurisdictions with both Northern Ireland and Republic of Ireland presenting higher mortality rates at some stage over the study period: Northern Ireland presented higher mortality rates at the start of the study and lower rates at the end of the study. This study observed that the cold period MI mortality rates amongst the 85+ year olds decreased by approximately 36% and 49% in the Republic of Ireland and Northern Ireland respectively. The MI mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figures 26b-d) within the older population.

The RD mortality rates for respiratory disease amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting higher mortality rates (see Figure 27a). The RD mortality rates amongst the 65-74 year olds showed an overall downwards trend in both jurisdictions (see Figure 27b). The Republic of Ireland presented higher mortality rates until the latter stages when the mortality rates were higher in Northern Ireland compared to the Republic of Ireland. This study reported that the RD mortality rates amongst the 65-74 year olds decreased by approximately 53% and 44% in the Republic of Ireland and Northern Ireland respectively. The RD mortality rates amongst the 75-84 year olds increased

during the early stages of the study before declining sharply in the latter stages of the study (see Figure 27c). The Republic of Ireland presented higher mortality rates compared to Northern Ireland over the study period. This study found that the RD mortality rates amongst the 75-84 year olds decreased by approximately 30% and 32% in the Republic of Ireland and Northern Ireland respectively. Amongst the 85+ year olds, the cold period RD mortality rates showed an overall downwards trend over the study period in both jurisdictions (see Figure 27d). Northern Ireland presented higher mortality rates over the study period with the exception of the years 2002/2003 when the trend was reversed. This study observed that the cold period RD mortality rates amongst the 85+ year olds decreased by approximately 19% and 33% in the Republic of Ireland and Northern Ireland respectively. The RD mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds (see Figures 27b-d) within the older population.

The mortality rates for COPD amongst the 18-64 year olds was very low and showed an overall downwards trend in both jurisdictions with the Republic of Ireland presenting higher mortality rates at the start of the study while this pattern reversed by the end of the study (see Figure 28a). The COPD mortality rates amongst the 65-74 year olds showed an overall downwards trend in both jurisdictions (see Figure 28b). The Republic of Ireland presented higher mortality rates until the latter stages of the study when this trend was reversed with Northern Ireland presenting the higher mortality rates. This study reported that the cold period COPD mortality rates amongst the 65-74 year olds decreased by approximately 61% and 6% in the Republic of Ireland and Northern Ireland respectively. The COPD mortality rates amongst the 75-84 year olds showed an overall downwards trend in the Republic of Ireland while there was an overall upwards trend in Northern Ireland over the study period (see Figure 28c). The COPD mortality rates were higher in the Republic of Ireland over the study period although there was some convergence of the mortality rates in both jurisdictions by the end of the study. This study observed that the cold period COPD mortality rates amongst the 75-84 year olds decreased by approximately 34% in the Republic of Ireland and increased by approximately 61% in Northern Ireland. The COPD mortality rates for amongst the 85+ year olds showed an overall downwards trend in the Republic of Ireland and an overall upwards trend in Northern Ireland over the study period (see

Figure 28d). The Republic of Ireland presented higher mortality rates than Northern Ireland. This study found that the cold period COPD mortality rates amongst the 85+ year olds decreased by approximately 9% in the Republic of Ireland and increased by approximately 55% in Northern Ireland. The COPD mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figures 28b-d) within the older population.

The mortality rates for pneumonia amongst the 18-64 year olds were very low and showed an overall downwards trend in both jurisdictions with Northern Ireland presenting slightly higher rates than the Republic of Ireland (see Figure 29). The pneumonia mortality rates amongst the 65-74 year olds showed an overall downwards trend in both jurisdictions (see Figure 29b). Northern Ireland presented higher mortality rates until the latter stages of the study when this trend was reversed with the Republic of Ireland presenting the higher mortality rates. This study reported that the mortality rates for pneumonia amongst the 65-74 year olds decreased by approximately 55% and 74% in the Republic of Ireland and Northern Ireland respectively. The pneumonia mortality rates amongst the 75-84 year olds showed an overall downwards trend over the study period in both jurisdictions (see Figure 29c). Northern Ireland presented higher mortality rates until the latter stages of the study when this trend was reversed with the Republic of Ireland presenting the higher mortality rates although there was a convergence of the rates at the end of the study. This study observed that the pneumonia mortality rates amongst the 75-84 year olds decreased by approximately 40% and 66% in the Republic of Ireland and Northern Ireland respectively. The cold period pneumonia mortality rates amongst the 85+ year olds showed an overall downwards trend in both jurisdictions (see Figure 29d). Northern Ireland presented higher mortality rates during the early and final stages of the study while the Republic of Ireland presented higher mortality rates during the latter stages of the study. This study found that the pneumonia mortality rates amongst the 85+ year olds decreased by approximately 35% and 51% in the Republic of Ireland and Northern Ireland respectively. The pneumonia mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds in both jurisdictions (see Figures 29b-d) within the older population.

The mortality rates for stroke amongst the 18-64 year olds showed an overall downwards trend in both jurisdictions with Northern Ireland presenting slightly higher mortality rates than the Republic of Ireland and the rates showed a slight increase at the end of the study in Northern Ireland (see Figure 30a). Those mortality rates were very low overall in both jurisdictions. The stroke mortality rates amongst the 65-74 year olds declined across the study period in both jurisdictions, with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 30b). This study observed that the stroke mortality amongst the 65-74 year olds decreased by approximately 73% and 67% in the Republic of Ireland and Northern Ireland respectively. The stroke mortality rates amongst the 75-84 year olds declined over the study period; with Northern Ireland presenting higher mortality rates than the Republic of Ireland (see Figure 30c). The study reported that the mortality rates for stroke amongst the 75-84 year olds decreased by approximately 58% in both jurisdictions. The stroke mortality rates amongst the 85+ year olds showed an overall downwards trend in both jurisdictions (see Figure 30d). The Republic of Ireland presented higher mortality rates in the early stages of the study while Northern Ireland presented higher mortality rates from the middle of the study onwards. This study found that the cold period stroke mortality rates amongst the 85+ year olds decreased by approximately 49% and 34% for Republic of Ireland and Northern Ireland respectively. The stroke mortality rates were highest amongst the 85+ year olds and lowest amongst the 65-74 year olds (see Figures 30b-d) within the older population.

3.2.7 Summary of jurisdictional differences in the mortality rates

The mortality rates showed an overall downwards trend in both jurisdictions except for COPD mortality which increased in Northern Ireland. The annual mortality rates and the summer/winter mortality rates were higher in Northern Ireland except for COPD. During the winter months, the mortality rates for CVD, MI, IHD and COPD were higher amongst males while RD, pneumonia and stroke mortality were higher amongst females in both jurisdictions. The mortality rates for all-cause mortality were comparable amongst the genders. The winter mortality rates amongst the different older age groups showed an overall decline in both jurisdictions and mortality rates amongst the 65-74 year olds were higher in Northern Ireland except for RD mortality and COPD mortality. The mortality rates amongst the remaining older age groups were higher in

the Republic of Ireland. COPD mortality was higher in all age groups in the Republic of Ireland. Similar patterns and trends were observed during the cold period with the mortality rates greater in both jurisdictions.

3.3 Temperature metrics

The temperatures in Northern Ireland were lower than those observed in the Republic of Ireland, with the temperatures in winter in Northern Ireland being nearly 1°C less than those in the Republic of Ireland (see Table 15). This trend of lower temperatures in Northern Ireland was reflected across the seasons and the temperature metrics. The mean of the maximum temperature was 10°C during the cold period and 8.6°C in the winter months for all of the weather stations in the Republic of Ireland. Meanwhile the mean of the maximum temperature was 9.1°C and 7.6°C during the cold period and winter months respectively in Northern Ireland. The above results were presented in the co-authored publication in Appendix 2.

3.4 Cold weather-mortality associations

3.4.1 Weekly lagged associations during the cold period in the Republic of Ireland

Table 16 presented the estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period for all ages 18+ years over the study period. All-cause mortality showed the greatest increase associated with cold temperatures in the preceding week to death of 1.3% (95% CI: 1.1%-1.5%) with the impact of cold temperature on mortality weakening by approximately 40% in the second week and continuing to weaken. The associations persisted up to 5 weeks prior to death (see Table 16). Similar associations were reported for CVD mortality with an increase of 1.5% (95% CI: 1.1%-1.9%) in the week preceding death; however associations were observed up to the preceding 4 weeks prior to death. IHD mortality showed the greatest increase of 1.6% (95% CI: 1.2%-2.1%) associated with cold temperature in the preceding week to death. IHD mortality presented similar trends to CVD mortality and also persisted up to the preceding 4 weeks prior to death. MI mortality showed comparable increases and trends to both IHD mortality and CVD mortality, persisting up to the preceding 4 weeks prior to death. RD mortality presented the strongest increase of 2.0% (95% CI: 1.5%-2.5%) with regards to temperatures 2 weeks prior to death; the associations were strong in week 1 and

remained strong in weeks 3-5 weeks prior to death. COPD mortality showed the greatest increase of 2.0% (95% CI: 1.2%-2.9%) in the preceding 4 weeks prior to death; with strong associations in weeks 1-3. The associations for COPD mortality did not extend into week 5. Pneumonia mortality showed the greatest increase of 2.0% (95% CI: 1.2%-2.8%) in the preceding weeks 2 and 3 prior to death. The associations were strong in weeks 1 and 4 but they did not extend into 5 weeks prior to death. Stroke mortality showed the greatest increase of 1.8% (95% CI: 1.1%-2.6%) associated with cold temperatures in the preceding week to death; the impact of cold temperatures on mortality weakened but lasted up to 3 weeks prior to death. There were no important associations in weeks 2, 4 and 5. Some of the above results were presented in the co-authored publication in Appendix 2.

3.4.2 Cumulative associations during the cold period in the Republic of Ireland

In the Republic of Ireland, the cumulative increases in mortality were calculated over the 5 week period for all-cause mortality and all respiratory diseases; for a 4-week period for CVD mortality, IHD mortality, MI mortality, COPD mortality and pneumonia mortality; and over the preceding 3 weeks for stroke mortality. The cumulative increase for all-cause mortality was 3.7% (95% CI: 2.6%-4.8%), 3.7% (95% CI: 2.2%-5.3%) for CVD mortality, 3.4% (95% CI: 1.6%-5.2%) for IHD mortality and 3.6 (95% CI: 1.5%-5.7%) for MI respectively (see Table 16). Increases for RD mortality were twice as large at 7.5% (95% CI: 4.8%-10.2%). COPD mortality showed cumulative increases of 7.1% (95% CI: 3.6%-10.5%). The cumulative increase for mortality from pneumonia mortality was 7.2% (95% CI: 4.0%-10.4%). Stroke mortality showed a cumulative increase of 3.1% (95% CI: 1.0%-5.3%) over a 3 week period.

3.4.3 Weekly lagged associations during the cold period in Northern Ireland

In Northern Ireland, all-cause mortality showed its greatest increase of 1.4% (95% CI: 1.1%-1.8%) with temperatures in the preceding week prior to death; with the impact of cold temperatures on mortality weakening but persisting up to 4 weeks prior to death (see Table 17). CVD mortality showed its strongest increase of 1.1% (95% CI: 0.6%-1.7%) in week 1 with important associations in week 3. The associations did not extend beyond week 3 and there were no important associations in week 2. IHD and MI mortality reflected similar patterns to CVD mortality, with their strongest increases of

1.4% (95% CI: 0.7%-2.1%) and 1.5% (95% CI: 0.8%-2.2%) respectively in the preceding week to death; with strong associations remaining in week 3. RD mortality showed the strongest increase of 2.6% (95% CI: 1.8%-3.4%) in the preceding week to death; with strong associations remaining until week 3. COPD mortality showed an increase of 3.7% (95% CI: 2.1%-5.3%) in the preceding week to death and remained strong to week 2. The associations did not persist after week 2. Pneumonia mortality showed its strongest increase of 2.8% (95% CI: 1.8-3.7%) in week 3, with strong associations in the preceding weeks. The associations did not persist after week 3. Stroke mortality showed important associations up to week 4 with its strongest association of 1.4% (95% CI: 0.4%-2.3%) in the preceding week death.

3.4.4 Cumulative associations during the cold period in Northern Ireland

Cumulative mortality increases for Northern Ireland were calculated for associations with cold temperatures in the 4 weeks before death for all-cause mortality and stroke mortality (see Table 17). Important associations were observed up to the preceding week 3 for CVD mortality, IHD mortality, RD mortality and pneumonia mortality; and up to 2 weeks preceding to death for COPD mortality, with the cumulative increases only calculated over these periods. The cumulative increases for all-cause mortality, CVD mortality, IHD mortality, MI mortality, RD mortality, COPD, pneumonia and stroke were 3.1% (95% CI: 1.8%-4.4%), 2.4% (95% CI: 0.7%-4.1%), 2.5% (95% CI: 0.3%-4.6%), 2.6% (95% CI: 0.6%-4.6%), 7.1% (95% CI: 4.8%-9.4%), 5.5% (95% CI: 1.9%-5.8%), 6.6% (95% CI: 3.7%-9.5%) and 4.2% (95% CI: 0.4%-8.0%) respectively.

3.4.5 Weekly lagged associations in the winter months in the Republic of Ireland

Table 18 presented the estimated percentage change per 1°C decrease in maximum temperatures in the Republic of Ireland in the winter months for the ages of 18+ years, 1984-2007. All-cause mortality showed the greatest increase 1.8% (95% CI: 1.5%-2.1%), in the preceding week to death (week 1), with the associations remaining strong but diminishing and persisting up to week 5 prior to death. CVD mortality showed the greatest increase of 1.8% (95% CI: 1.3%-2.3%) in the preceding week to death; with the associations remaining strong although diminishing and extending up to week 4 prior to death. IHD mortality followed a similar trend to CVD mortality, with its strongest increase of 2.1% (95% CI: 1.5%-2.7%) in the week prior to death. MI mortality

reflected a similar trend to both CVD and IHD mortality with its strongest increase of 1.9% (95% CI: 1.2%-2.7%) in the week preceding death (week 1). RD mortality showed its strongest increase of 3.2% (95% CI: 2.5%-3.9%) in week 2, with strong but diminishing associations persisting up to week 5. The associations for both COPD and pneumonia mortality also persisted up to week 5, with their strongest increases of 2.9% (95% CI: 1.7%-4.0%) and 3.6% (95% CI: 2.6%-4.7%) in week 4 and week 2 respectively. Stroke mortality had its greatest increase of 2.5% (95% CI: 1.5%-3.5%) in the week prior to death. The associations remained strong and extended to week 3. The above results were included in the co-authored published paper (see Appendix 2).

3.4.6 Cumulative associations in the winter months in the Republic of Ireland

The cumulative increases for the Republic of Ireland were calculated over the 5-week period for all-cause mortality, RD mortality, COPD and pneumonia mortality; over the 4-week period for CVD mortality, IHD mortality, and MI mortality and over the preceding 3 weeks for stroke mortality (see Table 18). This study reported that the 5-week cumulative increases for all-cause mortality, RD mortality, COPD and pneumonia mortality were 6.4% (95% CI: 4.8%-7.9%), 12.5% (95% CI: 8.9%-16.2%), 11.7% (95% CI: 6.0%-17.4%) and 13.8 (95% CI: 8.4%-19.1%) respectively. CVD mortality, IHD mortality and MI mortality showed cumulative increases of 5.6% (95% CI: 3.5%-7.7%), 5.3 (95% CI: 2.9%-7.8%) and 5.1% (95% CI: 2.2%-8.0%) respectively. The cumulative increase for stroke mortality was 5.0% (95% CI: 2.1%-8.0%). The above results were included in the co-authored published paper (see Appendix 2).

3.4.7 Weekly lagged associations in the winter months in Northern Ireland

All-cause mortality in Northern Ireland showed its strongest increase of 1.7% (95% CI: 1.3%-2.2%) occurring in the week prior to death (see Table 19). CVD mortality showed its strongest increase of 1.9 (95% CI: 1.2%-2.7%) in the week prior to death with the associations continuing to week 3. IHD mortality and MI mortality reflected comparable trends to CVD mortality, with their strongest increases of 2.3% (95% CI: 1.3%-3.2%) and 2.2% (95% CI: 1.2%-3.2%) respectively also occurring in the week preceding death.

The associations for RD mortality persisted up to 4 weeks prior to death, with the

strongest increases of 4.3% (95% CI: 3.2%-5.3%) occurring in week 3. COPD mortality showed its strongest increase of 3.9% (95% CI: 1.8%-6.0%) in week 3, with the associations not extending beyond week 3. Pneumonia mortality showed its strongest increase of 4.1% (95% CI: 2.8%-5.4%) in week 3. Stroke mortality showed the strongest increase of 2.0% (95% CI: 0.7%-3.3%) in the week preceding death and important associations persisted to week 3. The above results were included in the co-authored published paper (see Appendix 2).

3.4.8 Cumulative associations in the winter months in Northern Ireland

The cumulative increases for Northern Ireland were calculated for associations with cold temperatures in the 4 week period prior to death for RD mortality and pneumonia (see Table 19). Important associations were observed up to the preceding 3 weeks before death for the remaining cause-specific mortality groups and their cumulative increases were only calculated over those periods. The cumulative mortality increases for all-cause mortality, RD mortality and pneumonia mortality were 4.5% (95% CI: 3.2%-5.9%), 11.2% (95% CI: 7.1%-15.3%) and 10.2% (95% CI: 5.0%-15.4%) respectively. The cumulative mortality increases for CVD mortality, IHD mortality, MI mortality, COPD and stroke mortality were 3.9% (95% CI: 1.5%-6.3%), 3.8% (95% CI: 1.0%-6.6%), 3.7% (95% CI: 0.7%-6.7%), 10.6% (95% CI: 4.2%-17.0%), and 4.8% (95% CI: 0.9%-8.8%) respectively.

3.4.9 Cumulative associations for age stratification and gender during the cold period in the Republic of Ireland

Table 20 presented the estimated cumulative percentage change per 1°C decrease in the maximum temperatures in the Republic of Ireland during the cold period for the ages 18+ year olds, 1984-2007. Although there were some differences by age stratification and gender in the cold weather-mortality associations that were observed in the Republic of Ireland, this study found that those differences were not statistically important. There were no estimated mortality increases in the younger population (18-64 year olds). This trend was reflected amongst the 65-74 year olds with the exception of all-cause mortality which increased by 3.1% (95% CI: 0.8%-5.4%). Mortality increases were seen in the 75+ year olds for all-cause mortality, and each cause – specific groups. The greatest increase of 8.0% (95% CI: 4.4%-11.0%) was seen for RD

mortality and the smallest increase of 3.7% (95% CI: 0.8%-6.6%) was seen for stroke mortality. The estimated cumulative increases for COPD and pneumonia mortality were very comparable with increases of 7.4% (95% CI: 2.3%-12.5%) and 7.4% (95% CI: 2.8%-12.0%) respectively. All-cause mortality, CVD mortality, IHD mortality and MI mortality presented comparable estimated cumulating increases of 4.5% (95% CI: 3.0%-5.9%), 4.4% (95% CI: 2.3%-6.4%), 4.0% (95% CI: 1.5%-6.5%), and 4.2% (95% CI: 1.1%-7.2%) respectively in this age group. Estimated cumulated mortality increases were seen in both males and females for all-cause mortality and each cause specific mortality group except for stroke mortality, which was only seen in females. The mortality increases were slightly higher in females than males for all-cause mortality, CVD mortality, IHD mortality, MI mortality, RD mortality and COPD mortality. However, this trend was reversed for pneumonia mortality, where mortality increases were higher amongst the male population.

3.4.10 Cumulative associations for age stratification and gender during the cold period in Northern Ireland

In Northern Ireland, it was observed that there were some differences by age and gender in the cold weather-mortality associations; however those differences were not statistically important (see Table 21). The only estimated mortality increases were seen in the 18-64 year olds for all-cause mortality with an increase of 2.1% (95% CI: 0.0%-4.3%). Amongst the 65-74 year olds, there was an increase of 2.8% (95% CI: 1.0%-4.6%) for all-cause mortality. Mortality increases were seen in the 75+ year olds for all-cause mortality and each cause specific mortality group. The greatest increase of 5.9% (95% CI: 2.4%-9.3%) was seen for pneumonia mortality, closely followed by all respiratory mortality with an increase of 5.5% (95% CI: 3.4%-7.7%). All-cause mortality presented a mortality increase of 4.1% (95% CI: 2.9%-5.2%) amongst the 75+ year olds. The lowest mortality increase amongst this age group was observed for IHD mortality, with an increase of 3.5% (95% CI: 1.6%-5.4%). COPD mortality, MI mortality, CVD mortality and stroke mortality presented mortality increases of 3.5% (95% CI: 0.9%-6.0%), 3.6% (95% CI: 1.3%-5.9%), 3.7% (95% CI: 2.1%-5.2%) and 3.9% (95% CI: 0.05%-7.9%) respectively. Mortality increases were observed for all-cause mortality, RD mortality, COPD mortality and pneumonia mortality in both the male and female population; however, mortality increases were seen in the male

population only for CVD mortality. There were no statistically important mortality increases for IHD mortality, MI mortality or stroke mortality.

3.4.11 Cumulative associations for age stratification and gender in the winter months in the Republic of Ireland

Table 22 presented the estimated cumulative mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the winter months for the ages 18+ ages, 1984-2007. There were some differences by age stratification and gender in the cold weather-mortality associations that were observed in the Republic of Ireland; however, those differences were not statistically important. There were no estimated mortality increases in the 18-64 year olds. However, mortality increases were seen for all-cause mortality, CVD mortality, RD mortality and COPD mortality amongst the 65-74 year olds, with the largest increase of 10.8% (95% CI: 2.8%-18.8%) for RD mortality. Mortality increases were seen in the 75+ year olds for all-cause mortality and each cause-specific mortality group. The greatest mortality increase of 14.4% (95% CI: 8.5%-20.3%) was seen for pneumonia mortality while the lowest mortality increase of 5.6% (95% CI 1.7%-9.4%) was seen for stroke mortality. RD mortality and COPD mortality presented mortality increases of 12.9% (95% CI: 8.6%-17.1%) and 11.8% (95% CI: 4.5%-19.1%) respectively. These mortality increases were nearly double those for all-cause mortality, CVD mortality, IHD mortality and MI mortality, which presented increases of 7.7% (95% CI: 5.7%-9.7%), 6.3% (95% CI: 3.5%-9.2%), 6.4% (95% CI: 3.0%-9.7%), 6.1% (95% CI: 2.0%-10.2%) respectively. Mortality increases were observed for all-cause mortality and each cause-specific mortality groups for each gender except for stroke mortality which only presented important associations in the female population. This study found that the mortality increases were higher amongst the female population for all-cause mortality, IHD mortality, MI mortality, RD mortality and COPD mortality. Mortality increases were higher amongst the male population for CVD mortality and pneumonia mortality. The above results were included in the co-authored published paper (see Appendix 2).

3.4.12 Cumulative associations for age stratification and gender in the winter months in Northern Ireland

There were some differences by age stratification and gender in the cold weather-

mortality associations that were observed in Northern Ireland; however, those differences were not statistically important (see Table 23). There were no important increases observed amongst the 18-64 year olds for all-cause mortality and each cause-specific mortality group, with the exception of RD mortality which presented an estimated mortality increase of 15.3% (95% CI: 0.5%-30.2%). Important mortality increase of 4.5% (95% CI: 1.6%-7.3%), 12.8% (95% CI: 2.3%-23.2%) and 15.6% (95% CI: 2.6%-28.6%) were observed amongst the 65-74 year olds for all-cause mortality, RD mortality and COPD mortality respectively. With the exception of stroke mortality, important increases were seen in all-cause mortality, CVD mortality and pneumonia mortality amongst the 75 + year olds. The greatest increase of 10.4% (95% CI: 4.9%-15.8%) was observed for RD mortality and the lowest increase of 3.5% (95% CI: 0.1%-6.8%) was seen in CVD mortality. All-cause mortality and pneumonia mortality presented statistically important increases of 5.1 (95% CI: 3.3, 6.9) and 9.7 (95% CI: 2.4, 17.1) respectively. The greatest increases for RD mortality was observed in the 18-64 year olds; for COPD, it was the 65-74 year olds, while for all-cause mortality and CVD mortality, it was in the 75+ year olds. Statistically important increases were observed in both males and females for all-cause mortality, RD mortality and COPD mortality. Mortality increases were observed for CVD mortality, IHD mortality, MI mortality, and stroke mortality for males; and pneumonia for females. All-cause mortality showed greater mortality increases in males; while the mortality increases for all respiratory mortality and COPD mortality were greater amongst the females than males. The above results were included in the co-authored published paper (see Appendix 2).

3.4.13 Summary of the jurisdictional differences in the cold weather-mortality relationship

The cold weather-mortality associations were strongest in the week preceding death for all-cause mortality, CVD, MI, IHD and stroke and second week for RD mortality and pneumonia and the fourth week for COPD mortality in the Republic of Ireland while it was the first week in all mortality groups except for pneumonia (third week) in Northern Ireland during the cold period. The patterns were similar in the winter months except for COPD mortality in Northern Ireland which was strongest in the third week. The cold weather-mortality associations were more persistent in the Republic of Ireland,

extending up to 5 weeks prior to death and 4 weeks in Northern Ireland. The associations were strongest RD mortality in both jurisdictions with COPD mortality second strongest in the Republic of Ireland, and pneumonia in Northern Ireland. The associations were weakest for stroke mortality in the Republic of Ireland (cold period and winter months) and CVD mortality during the cold period and MI mortality in the winter months in Northern Ireland. The cold weather-mortality associations were stronger amongst females for all mortality groups except for RD and pneumonia mortality in the Republic of Ireland during the cold period and similar patterns were observed in the winter months except for CVD mortality which was greater amongst males and RD mortality which was greater amongst females. In Northern Ireland, stronger associations were observed in males for all-cause mortality and CVD mortality with no important associations observed in both genders for IHD, MI and stroke mortality. In the winter months, Northern Ireland observed similar patterns to the cold period except for IHD and MI mortality where important associations were reported amongst males. The Republic of Ireland presented stronger associations than Northern Ireland amongst the 75+ year olds for all mortality groups except for stroke mortality where the associations were higher in Northern Ireland during the cold period. The Republic of Ireland reported stronger associations for RD mortality amongst the 75+ year olds while in Northern Ireland it was amongst the 18-64 year olds. This pattern was repeated in the winter months. Northern Ireland observed stronger associations amongst the 18-64 year olds than the Republic of Ireland.

4.0 DISCUSSION

This study examined and compared the excess winter mortality rates for all-cause and each cause-specific mortality group by age and gender on the island of Ireland over a 20-year period. It also assessed the association of cold weather on all-cause and cause-specific mortality in both jurisdictions (Republic of Ireland and Northern Ireland), and assessed for effect modification of the cold weather-mortality relationship by age and gender over a 24-year period.

This study was unique for several reasons. It is the first study in Europe to consider the case-crossover approach, using daily maximum temperature as its temperature metric and applying a longer lag structure over a longer study period with a large population sample. It also assessed for effect modification by age and gender and reported on the associations between cold weather and COPD, pneumonia and stroke mortality as well as other cause-specific mortality groups. It was the first international study to compare two adult populations from different governmental jurisdictions within the island of Ireland over a long study period and using an extensive dataset.

This MPhil study was part of collaboration between Brunel University and the Centre of Ageing Research and Development in Ireland, Dublin Institute of Technology and the Institute of Public Health in Ireland. The analysis and findings of the first part of this study on mortality rates have been published in Chapter 4 of an international collaborative report, 'Fuel poverty, older people and cold weather: all all-island analysis', of which the researcher was a co-author (see Appendix 1).

The analysis and findings of the second part of this study, which considered the association of cold weather on mortality on the island of Ireland were published in a paper 'The association of cold weather and all-cause and cause-specific mortality in the island of Ireland between 1984 and 2007' in Environmental Health journal. The researcher was a co-author of the aforementioned paper (see Appendix 2). This was a highly accessed paper.

4.1 Mortality rates

Some of the findings from this study have been included in Chapter 4 of an international

report, 'Fuel poverty, older people and cold weather: all all-island analysis' (Goodman *et al.* 2011) and this can be found in Appendix 1. This study observed that the annual mortality rates for all-cause mortality, CVD mortality, MI mortality and stroke mortality declined across study period in both jurisdictions. Respiratory and pneumonia mortality rates showed an overall downward trend over the study period in both jurisdictions and reflected a downward trend in mortality rates seen by other studies over the last few decades (Layte *et al.* 2011; Morgan *et al.* 2007; Unal *et al.* 2004). The annual mortality rates from COPD mortality declined in the Republic of Ireland while it increased in Northern Ireland. Northern Ireland presented overall higher annual mortality rates from all-cause mortality, CVD mortality, MI mortality, IHD mortality and stroke mortality. Northern Ireland also experienced greater rates of decline in respiratory mortality and pneumonia mortality during the first half of this study period, these rates declining towards the end of the study.

This study observed an overall downward trend in both the summer and winter mortality rates from all-cause mortality and each cause specific mortality groups except for COPD mortality which witnessed an increase in the rates for Northern Ireland only. This study reported excess winter mortality with the winter mortality rates noticeably higher than summer mortality rates in all-cause mortality and in each cause-specific mortality groups in both jurisdictions. There was some convergence of the summer and winter mortality rates from all-cause mortality, CVD mortality, MI mortality and pneumonia mortality. Northern Ireland displayed higher mortality rates in the Republic of Ireland in the winter months for all-cause mortality, MI mortality, IHD mortality, RD mortality, pneumonia mortality and stroke mortality for all ages; except for COPD mortality where the Republic of Ireland presented higher rates until the later stages of the study when the rates were higher in Northern Ireland. The male population presented overall higher summer and winter mortality rates for all-cause mortality, CVD mortality, IHD mortality, MI mortality, RD mortality and COPD mortality while pneumonia mortality and stroke mortality rates were higher amongst females in both jurisdictions.

The mortality rates for all-cause mortality and each cause-specific mortality group were

the highest amongst the 85+year-olds and lowest amongst the 65-74 year-olds, with very low rates amongst the 18-64 year olds. Northern Ireland presented overall higher winter mortality rates for all-cause mortality in each age group. CVD mortality, MI mortality and IHD mortality rates were higher Northern Ireland for the 65-74 year-olds while this trend was reversed in the other age groups with the rates higher in the Republic of Ireland. COPD mortality rates were higher overall in the Republic of Ireland in each age group. Pneumonia mortality and stroke mortality were higher in all age groups in Northern Ireland. Similar trends and patterns were reflected during the cold period although the mortality rates were higher in both jurisdictions.

The differences in mortality rates between the two jurisdictions have narrowed over time (Goodman *et al.* 2011). Some of the differences observed in Northern Ireland and the Republic of Ireland might be explained by systematic differences in the coding of deaths; however this would not explain all of the observed differences (Goodman *et al.* 2011). There may be a myriad of other factors giving rise to this, for example, diet, health care, public health policies and interventions and housing conditions (Goodman *et al.* 2011).

The fall in mortality rates, both annual and winter, on the island of Ireland may be due to a number of factors. The suggestion that milder winters (Walsh 2007) may have had an effect on the fall in death rates is not borne out by the temperature data, which does not reflect the decline witnessed in mortality post 1999 (Layte *et al.* 2011). Coronary Heart Disease (CHD) mortality decreased by more than 50% between 1981 and 2000 in England and Wales; with approximately 40% of the UK decrease attributable to the combined effects of modern cardiological treatments and almost 60% reduction in major risk factors, particularly smoking (Unal *et al.* 2004). These mortality reductions not only reflected a substantial decline in smoking prevalence but also smaller reductions in mean blood pressure, total cholesterol and deprivation (Unal *et al.* 2004). This trend may have been reflected on the island of Ireland with their falling mortality rates.

The majority of the decrease in mortality between 1985 and 2000 is attributed to changes in lifestyle factors but it is important to note that all the main population risk

factors for cardiovascular disease - smoking, physical activity, obesity, diabetes and population blood pressure, have all worsened in Ireland since 2000 with the exception of population cholesterol and so cannot explain the abrupt change in mortality trends (Morgan *et al.* 2007). Across almost all CHD medications between the period 1995 to 2005, there was a gradual increase from the beginning of the series followed by a steepening increase after 1999, and a further change in the prescribing trend post- 2007 (Layte *et al.* 2011). The Irish cardiovascular strategy, provide a structured approach to the primary and secondary prevention of cardiovascular disease in Ireland (Department of Health and Children 1999). The strategy included prescribing protocols for GPs, contributing to a steep increase in the volume of cardiovascular drugs prescribed, with beta-blockers increasing by 109%, ace inhibitors by 89% and statins by 206% between the summer of 1999 and the end of 2003 (Layte *et al.* 2011).

4.2 Cold weather-mortality associations

This study found that the cold weather-mortality associations persisted up to 5 weeks and 4 weeks preceding death in the cold period and winter months in the Republic of Ireland and Northern Ireland respectively. Strong associations were reported between the exposures to cold temperatures and estimated increased mortality on the island of Ireland over a period of 24 years, with some differences in the persistence and pronouncement of those associations between the two jurisdictions. The cold weather-mortality associations were more persistent overall in the Republic of Ireland, with similar patterns observed in both jurisdictions.

In the winter months, this study showed that the all-cause mortality associations were strongest in the week preceding death in both jurisdictions; diminishing but persisting up to five weeks in the Republic of Ireland and three weeks in Northern Ireland. The cold weather-CVD mortality associations showed similar patterns to all-cause mortality, with the strongest associations in the week prior to death in both jurisdictions. The associations diminished but extended up to 4 weeks in the Republic of Ireland and three weeks in Northern Ireland. The cold weather-mortality associations were more pronounced in the Republic of Ireland than in Northern Ireland. The Republic of Ireland reported cumulative estimated increases in all-cause mortality and CVD mortality of 6.4% and 5.6% per 1°C decrease in the daily maximum temperature over five weeks

and four weeks respectively; in Northern Ireland the respective associations showed estimated increases of 4.5% and 3.9% respectively over three weeks.

IHD mortality associations were strongest in the week preceding death and followed a similar pattern to CVD and all-cause mortality, with associations extending up to 5 weeks in the Republic of Ireland and the four weeks in Northern Ireland. The Republic of Ireland observed a cumulative estimated increase of 5.3% while Northern Ireland reported a cumulative increase of 3.8%. MI mortality associations followed a similar pattern to CVD mortality and IHD mortality extending up to 4 weeks preceding death in the Republic of Ireland and three weeks Northern Ireland; and the cumulative associations were very comparable with the CVD and IHD mortality associations.

RD mortality showed the strongest associations in the second week preceding death with the associations extending up to 5 weeks prior to death in the Republic of Ireland and three weeks preceding death in Northern Ireland with the associations not persisting beyond the third week in Northern Ireland. The cold weather-respiratory mortality associations were more pronounced in the Republic of Ireland; with cumulative associations of 12.5% and 11.2% in the Republic of Ireland and Northern Ireland respectively. The RD mortality associations were approximately twice those of all-cause mortality and more than twice those of CVD mortality in both jurisdictions.

The COPD associations were strongest four weeks prior to death in the Republic of Ireland and three weeks preceding death in Northern Ireland, with the associations not persisting beyond those weeks. The study reported an estimated cumulative increase in COPD mortality of 11.7% in the Republic of Ireland and 10.6% in Northern Ireland and these associations were similar to respiratory mortality. Pneumonia mortality associations were strongest in the second week preceding death in the Republic of Ireland and third week in Northern Ireland with the associations persisting up to 5 weeks and four weeks prior to death the Republic of Ireland and Northern Ireland respectively. The Republic of Ireland reported a cumulative mortality association of 13.8% while Northern Ireland showed an increase of 10.2%. The stroke mortality increases were strongest in the week preceding death, extending up to 3 weeks in both jurisdictions. The cold weather-stroke mortality associations showed an estimated

increase of 5% and 4.8% in the Republic of Ireland and Northern Ireland respectively.

This study observed that RD mortality was more pronounced than CVD mortality or all-cause mortality while the all-cause mortality associations were greater than CVD mortality associations in both jurisdictions. Pneumonia mortality showed the most pronounced associations in the Republic of Ireland while in Northern Ireland it was RD mortality. The least pronounced associations were observed for stroke mortality in the Republic of Ireland and MI mortality in Northern Ireland. The cold weather-mortality associations were more pronounced and more prolonged in the winter months compared to the cold period. In particular, the associations were more prolonged for COPD mortality and pneumonia mortality during the winter months in the Republic of Ireland and for RD mortality, COPD mortality and pneumonia mortality in Northern Ireland (see Tables 16-19). These findings have been highlighted in the co-authored published paper (see Appendix 2).

The cold weather-mortality relationship was less persistent for COPD and pneumonia mortality during the cold period compared to the winter months in the Republic of Ireland, with the remaining mortality causes showing similar persistence in the two seasons. There were some subtle differences in Northern Ireland with the associations for all-cause mortality being more persistent in the cold period than the winter months, extending up to 4 weeks preceding death. The CVD, IHD and MI mortality associations in the cold period displayed comparable patterns to those in the winter months. COPD mortality and pneumonia mortality were less persistent in the cold period whereas stroke mortality was more persistent. The associations for all-cause and each cause-specific mortality group were not as strong in the cold period as in the winter months. RD mortality was the strongest in the cold period in the Republic of Ireland while in the winter months, it was pneumonia. In Northern Ireland, pneumonia mortality was the second strongest during the period whereas it was COPD mortality in the winter months.

These findings are consistent with a previous Irish study (Goodman *et al.* 2004) which examined the relationship between cold weather and mortality in Dublin over a period of 17 years, using Poisson regression models. They reported mortality increases for all-

cause mortality (2.6%), cardiovascular disease (2.5%), and respiratory disease (6.7%) in relation to 1°C decrease in mean daily temperatures up to 40 days preceding death (Goodman *et al.* 2004). Similar results were observed in Scotland for all-cause mortality, cardiovascular disease and respiratory mortality with cold temperatures during the month prior to death (Carder *et al.* 2005; Gemmell *et al.* 2000). Multi-city studies in Europe and the US reported similar increases for all-cause and cause-specific mortality from cold weather during winter and the persistence of those associations, with similar lag periods as presented here (Analitis *et al.* 2008; Anderson and Bell 2009; Zeka *et al.* 2014). Cold-related mortality was most associated longer lags (average the current day to 25 days previous) (Anderson and Bell 2009). An Australian study observed that the cold associations persist for 21 days preceding death (Yu *et al.* 2011a). A US study found similar prolonged associations (Braga *et al.* 2001). A study in Germany found that cold spells lead to excess mortality to relatively small degree which last for weeks (Laschewski and Jendritzky 2002).

A Scottish study observed that the associated increase in cardiovascular deaths was weakest but with a significant increase in mortality that lasted for three weeks (Gemmell *et al.* 2000). In the Netherlands, it was reported that a 1.7% increase in cardiovascular mortality in the 30 days after each 1°C temperature decrease was observed (Huynen *et al.* 2001). In Scotland IHD mortality increased by around 1% in the week of and the week after a 1°C decrease in temperature with little associations thereafter (Gemmell *et al.* 2000). A British study estimated that a 1°C reduction in temperature on a given day would cumulatively increase the risk of MI by 2.0% over the current and following 28 days, the strongest effects being estimated at the intermediate lags of 2-7 and 8-14 days (Bhaskaran *et al.* 2010).

Other studies have reported similar patterns and trends to those observed in this study. The cold effects and respiratory mortality were strongest 2 to 4 weeks after the cold event (Goodman *et al.* 2004). Winter respiratory deaths were reported to peak about 12 days after the cold spell (Keatinge 2002). In Scotland respiratory deaths increased by 1% 1 to 2 weeks after a decrease of 1°C in weekly mean temperature (Gemmell *et al.* 2000). In eight cold climate US cities, little association of cold temperatures on deaths from COPD or pneumonia was reported (Braga *et al.* 2002). General practitioner visits

by the elderly for respiratory disease in London found to rise by 10.5% for each 1°C drop in temperature (Hajat and Haines 2002). This study reported that the strongest observed associations were in week two preceding death in both jurisdictions which was comparable with other studies (Carder *et al.* 2005; Donaldson and Keatinge 1997; Goodman *et al.* 2004; Huynen *et al.* 2001). A Scottish study observed that the respiratory disease mortality associations were generally larger than the associations of temperature on all-cause mortality and cardiovascular disease mortality (Carder *et al.* 2005). They found that the strongest associations for respiratory disease mortality occurred at a temperature lag of 13-18 days (Carder *et al.* 2005).

Only a small number of studies have looked at the association between cold temperature on mortality from COPD, pneumonia and stroke (Zeka *et al.* 2014). An earlier study of 12 cold-climate US cities did not observe any increase in COPD mortality in relation to cold, but their reported increase for pneumonia mortality is comparable with those reported in this study (Braga *et al.* 2002; Zeka *et al.* 2014). Another US study reported elevated risk of dying of COPD associated with cold weather, in an elderly population (Schwartz 2005). A European study reported increases in stroke mortality associated with cold temperatures over 15 days before death (Analitis *et al.* 2008), and other studies in Russia and Asia reported similar findings (Atsumi *et al.* 2013; Hong *et al.* 2012; Revich and Shaposhnikov 2008).

The increased susceptibility of persons with COPD to dying on extremely cold days is noteworthy, although perhaps more explicable (Schwartz 2005). People with COPD often have cardiovascular complications, which may play a role on blood components (Schwartz 2005). A study in the United States found that people with COPD had elevated risks of dying 1.2% on cold days (Schwartz 2005). Although he reported an elevated risk of COPD exposure from exposure to cold temperatures, their associations were smaller than those observed in this study. Their study applied a short lag structure with a medium population study over a medium study period, which may not capture prolonged associations.

Few studies have considered the cold association on stroke mortality using a distributed

medium/long lag structure (Analitis *et al.* 2008; Atsumi *et al.* 2013; Liu *et al.* 2011; Revich and Shaposhnikov 2008; Yang *et al.* 2012). This study's findings showed that stroke mortality increases in the first 3 weeks preceding death. The cold weather-stroke mortality associations in this study were greater than those in some earlier studies (Analitis *et al.* 2008; Liu *et al.* 2011) and less than other studies (Revich and Shaposhnikov 2008; Yang *et al.* 2012). However, these differences for COPD and stroke mortality may be explained by the application of different lag structures over medium and longer term study periods in different geographic climate locations.

This study found that there were weaker cold temperature associations for CVD, IHD, MI and stroke mortality in the second week preceding death, with those cold-weather mortality associations recovering the following week. It is possible that the deaths observed in winter represent shifts in the timing of events that lead to deaths (mortality displacement), and that the effects of temperature simply serve to bring forward a death by a short period of time (Aylin *et al.* 2001). This phenomenon has been described previously as harvesting, which in simple terms, is likely due to the depletion in numbers by premature mortality of those most susceptible to cold weather (Aylin *et al.* 2001; Goodman *et al.* 2004; Schwartz 2000, 2001). The extended cold weather-mortality associations observed in this study suggested that there was potentially a cumulative health effect of cold weather and a gradual weakening and displacement by death (Schwartz 2000, 2001; Zeka *et al.* 2014), and were also evidenced by a small number of epidemiologic studies that have considered long lag structures (Analitis *et al.* 2008; Anderson and Bell 2009; Barnett *et al.* 2012; Donaldson and Keatinge 1997; Gemmell *et al.* 2000; Goodman *et al.* 2004).

Whilst this study examined different temperature metrics, stronger associations were reported for the application of maximum temperature in the models during both cold period and winter months in both jurisdictions. This is consistent with recent studies which suggested that maximum temperature is more likely to capture days that are consistently cold and extreme cold days (Atsumi *et al.* 2013; Diaz *et al.* 2005). However, it is acknowledged that when estimating the health effects of temperature, the choice of the temperature measure is of less importance compared with other model choices, such as the length of the longest exposure lag (Barnett and Astrom 2012).

4.3 Effect modification and stratification by age and gender

This study observed that the cold weather-mortality associations were generally greater in women than men in both jurisdictions. These findings were generally consistent with other studies (Barnett *et al.* 2005; Kysely *et al.* 2009; Yu *et al.* 2010), and however a study in China reported that the associations were higher males (Yang *et al.* 2012). Males were at a higher risk of cold associations than females but were not statistically important (Yang *et al.* 2012). However, they applied a different modelling design over a short study period using a shorter lag structure and to a medium population sample.

Another study observed weak evidence for modification of the cold association by age, but temperature-related mortality associations were not differential by gender (O'Neill *et al.* 2003). A Scottish study found little indication that the association of temperature on mortality was stronger in one age-group compared with another although they observed that there appeared to be a difference in the distribution of the lags with temperature associations persisting for longer in the older age group (Carder *et al.* 2005). Although their lag structure and study period was comparable, they did not indicate their population sample so it was not possible to determine if they used a comparable population sample.

A British study observed evidence of effect modification by age, those aged 75-84 years old apparently more vulnerable to temperature effects than other age groups (Bhaskaran *et al.* 2010). Few studies have investigated the associations of temperature on risk of MI in the older age group; on reporting an increased cold association amongst those aged more than 65 years old (Morabito *et al.* 2006) and a further study found no difference in the associations when restricting their analyses only to older age groups (Danet *et al.* 1999; Enquesselassie *et al.* 1993).

A study in China found statistically significant differences in effect modification between the oldest (85+ year olds) and the youngest (less than 65-year-olds) (Yang *et al.* 2012). Another study found stronger cold-related associations on mortality for those younger than 65 years old (O'Neill *et al.* 2003), and it was reported a qualitatively similar relation between weather and mortality same age-group (Curriero *et al.* 2002). In

general, reports in Europe show that the elderly are more sensitive (Ballester *et al.* 1997; Keatinge *et al.* 2000; Wilkinson *et al.* 2001; Wilkinson *et al.* 2004).

These studies have applied different modelling approaches to different study periods using varying distributed lag structures with different population samples in different climate settings and may help to explain some of the differences in their findings.

4.4 Physiological effects of cold weather exposure

This study observed that there were strong associations with increased mortality due to exposure to cold temperatures, with the cold weather-mortality relationship persisting up to 5 weeks preceding death. These findings are physiologically plausible and it is conceivable that the lags for the associations of low temperatures may vary on mortality in length for different death categories (Carder *et al.* 2005). Cold weather alone causes striking short-term increases in mortality, mainly from increased cardiovascular, thrombotic and RD mortality (Donaldson and Keatinge 1997; Hampel *et al.* 2010). Overexertion in a cold environment may trigger surges in blood pressure that could lead to coronary plaque rupture and subsequent coronary thrombosis (Arntz *et al.* 2001).

Deaths such as myocardial ischaemia from increased work demands on the heart muscle or from increased formation of thrombus can occur in hours or days (Mercer 2003; Neild *et al.* 1994). The onset of acute MI has been related to the presence of a vulnerable plaque, plaque disruption and fissuring and superimposed thrombosis (Fuster *et al.* 1992). Several physiologic changes have been identified which may increase the probability of these events (Muller *et al.* 1994). Elevated lipid levels (Brown *et al.* 1993) and the presence of active inflammation (Berk *et al.* 1990) may make plaques more vulnerable to rupture (Sheth *et al.* 1999). Disruption of plaques may be precipitated by hemodynamic forces, especially increases in blood pressure (Gertz and Roberts 1990) subsequent thrombosis may be accelerated by higher levels of fibrinogen and other pro-coagulants (Rosito and Tofler 1996). It has been shown that serum cholesterol (Gordon *et al.* 1987), C-reactive protein (Woodhouse *et al.* 1994), blood pressure (Brennen *et al.* 1982), fibrinogen (Stout and Crawford 1991; Woodhouse *et al.* 1994), and factor VII activity (Woodhouse *et al.* 1994) are all higher in the winter. Elevation of these parameters may contribute to an increased tendency towards arterial

thrombosis and a higher winter incidence of acute coronary syndromes (Muller *et al.* 1994). Direct exposure to cold and, probably, respiratory cross infections are responsible for most excess winter mortality (Donaldson and Keatinge 1997). Measures to reduce cold exposure therefore provide the clearest means of preventing IHD and probably RD mortality in winter (Donaldson and Keatinge 1997).

These findings show that the cold weather-mortality relationship is strongest in the older population (75+ year olds), which are physiologically plausible. Previous studies have indicated mechanisms such as reduced skin blood flow and smaller increases in cardiac output, which can compromise thermoregulation (Basu 2009; Bouchama and Knochel 2002; McGeehin and Mirabelli 2001). Exposure to cold is greater among poorer individuals and the elderly have lower income levels than other age groups (Sheth *et al.* 1999) and these may affect their ability to afford to keep their homes warm in colder weather. Alternatively, the elderly may demonstrate exaggerated responses to winter weather conditions, with greater increases in blood pressure and coagulation parameters, or a greater likelihood of infection (Collins *et al.* 1985). Blood pressure may vary more among elderly people between winter and summer (Ballester *et al.* 1997; Woodhouse *et al.* 1993) with increased blood pressure in the winter.

4.5 Jurisdictional differences

This study reported that there were comparable trends in the declining mortality rates and excess winter mortality, and the cold weather-mortality relationships in both jurisdictions albeit with some subtle differences. It is difficult to quantify the rationale for these small differences which were observed. However, it is suggested that the different public health policies and healthcare systems in the two jurisdictions may have an influence on the population mortality and response to cold weather (Zeka *et al.* 2014). There are currently winter fuel allowances and cold weather payments, which target vulnerable population groups in both jurisdictions; however, these schemes differ substantially from each other (Department of Social Protection 2014; NI Direct 2013; The Marmot Review Team 2011; The United Kingdom Parliament 2013). It has been suggested that the fuel allowance was not sufficient in meeting home-heating costs in the Republic of Ireland, and this was likely due to the contribution of poor thermal efficiency and low household income (Healy and Clinch 2004).

In colder climates, it has been suggested that the maintenance of warmth in houses has a protective effect on winter mortality (Donaldson *et al.* 1998; Eng and Mercer 1998). One possible reason for the much lower excess winter mortality in Norway, compared with England and Wales may be that the heating is usually included in the rent (Laake and Sverre 1996); consequently, poor households should have a warm indoor environment (Aylin *et al.* 2001). The European household panel survey showed that the proportion of households in the UK and Ireland that reported being unable to keep their homes adequately warm was more than five times that in Germany (Whyley and Callender 1997). A British study found a link between seasonal variation deaths from heart attacks and strokes and quality housing in England (Wilkinson *et al.* 2001).

The effectiveness of these cold weather and winter fuel payments in Northern Ireland aimed at reducing winter mortality have not been examined (Zeka *et al.* 2014). Rising fuel prices and demographic changes, combined with the economic recession have contributed to high levels of fuel poverty such as older people, those living alone and lone parent households (Goodman *et al.* 2011; Healy 2003; McAvoy 2007; Walker *et al.* 2013). The jurisdictional differences in housing stock, insulation and heating, also related to socioeconomic deprivation, influence the extent of fuel poverty (Healy 2003; Healy and Clinch 2004; Walker *et al.* 2013). In addition, differences in the identification of the ‘fuel poor’ and ‘those most in need’ can also impact upon the effectiveness and differences of the schemes in the two jurisdictions (Dubois 2012; Healy 2003; Liddell *et al.* 2012; Zeka *et al.* 2014).

A very strong relationship has been observed between the incidence of fuel poverty, social class, geographic and demographic patterns of those susceptible on the island of Ireland (Healy and Clinch 2004; Walker *et al.* 2013). The number of older people, who are vulnerable to ill-health from cold homes, will increase as part of significantly aging population in both jurisdictions (Goodman *et al.* 2011). Currently there is a concentration of fuel poverty among rural older person households in Northern Ireland while fuel poverty is highest in most urbanised and very rural areas in the Republic of Ireland (Goodman *et al.* 2011; Healy and Clinch 2004). A greater proportion of older people in Northern Ireland live alone and in social housing when compared to the

Republic of Ireland (Goodman *et al.* 2011). Jurisdictional differences in the general population health status, provision of and access to health care, and distribution of health and social inequalities, potentially contribute in concurrence with these policies, and may explain some of the observed differences in the cold weather-mortality associations between the two jurisdictions (Zeka *et al.* 2014).

It is important to recognise that climate change induced weather patterns will effect long-term cold weather-mortality relationship (Zeka *et al.* 2014). Research suggests that increasing global mean temperatures will do little to reduce morbidity and mortality in winter (Ebi and Mills 2012; Field *et al.* 2014; Kinney *et al.* 2012; Staddon *et al.* 2014), likely due to increases in temperature variability and weather extremes. These weather patterns have also been observed on the island of Ireland in the past few decades (Met Eireann 2014a; The United Kingdom Met Office 2014b), on this basis only , it may be possible that winter mortality will change over time (Zeka *et al.* 2014). However, whether this change will be an increase or decrease is much more complex and multifaceted and will depend on how rapidly the climate changes, how quickly the population adapt, and on infrastructural and policy interventions, and remains a challenge particularly in view of the aging population on the island of Ireland (Zeka *et al.* 2014). Additional analyses were carried out in this study to examine the cold weather-mortality relationship for different time periods in each jurisdiction in order to understand the long term patterns of the cold weather-mortality association (Zeka *et al.* 2014). The findings suggested a slight diminishing of cold weather-mortality relationship in both jurisdictions over time; however, they need to be interpreted with caution, considering the complexity of the relationship of mortality and cold winters and the influence of the societal factors discussed earlier (Zeka *et al.* 2014).

5.0 CONCLUSIONS AND RECOMMENDATIONS

This study found that although the population has increased in both jurisdictions on the island of Ireland, including the older population and life expectancy, mortality has declined significantly over 20 years. Northern Ireland presented higher annual mortality rates for all-cause mortality and each cause-specific mortality group except for COPD which was higher in the Republic of Ireland but the differences have narrowed significantly over time. These patterns in the mortality rates were reflected during the winter months and cold period.

Despite falling mortality rates, excess winter mortality was still evident in each jurisdiction. The mortality rates amongst the 65-74 year olds were generally higher in Northern Ireland while the 75-84 year olds and 85+ year olds displayed higher mortality rates in the Republic of Ireland. Similar patterns were observed for male and female populations. The highest mortality rates were observed for all-cause mortality and CVD mortality whilst the lowest were reported for COPD mortality.

This study suggested that there were strong associations between the exposure to cold temperatures and increased mortality over 24 years on the island of Ireland and between two different jurisdictions with the associations persisting up to 35 days and 28 days preceding death in the Republic of Ireland and Northern Ireland respectively. This study confirmed upon previous studies, which have examined the cold associations on all-cause mortality, CVD and RD mortality (Analitis *et al.* 2008; Anderson and Bell 2009; Barnett *et al.* 2012; Carder *et al.* 2005; Gemmell *et al.* 2000; Goodman *et al.* 2004; Huynen *et al.* 2001); and extends upon the findings of a previous Irish study to the whole of the Irish Republic and Northern Ireland, using the most extensive dataset to date on the island of Ireland.

This study confirmed the previous findings of prolonged associations using extended distributed lag structure in a temperate climate under the influence of the Gulf Stream jet stream. The cold weather-mortality associations were more pronounced and persistent in the Republic of Ireland with associations strongest for COPD, pneumonia and RD mortality in both jurisdictions. This study observed that the cold weather-

mortality associations were greater in women than men in both jurisdictions. The extended cold weather-mortality associations suggested that there was potentially a cumulative health effect of cold weather and a gradual weakening and displacement by death (Goodman *et al.* 2004; Schwartz 2000, 2001; Zeka *et al.* 2014).

The strong and persistent cold weather-mortality relationship highlights that the estimated increased mortality from exposure to cold temperatures in both jurisdictions is an important and topical public health issue. As the island of Ireland currently has the highest levels of excess winter mortality in Europe, with an estimated 2,800 excess deaths during each winter (McAvoy 2007), the key challenges are to develop and implement policies which tackle fuel poverty and reduce winter morbidity and mortality (Zeka *et al.* 2014). The fact that some differences in cold weather-mortality patterns are observed between the two jurisdictions, albeit small, suggests that policies and their implementation, and other societal factors potentially play a key role in determining population health patterns (Zeka *et al.* 2014).

This study observed little effect on the cold weather-mortality relationship over time in both jurisdictions. However, the temporal separation in those preliminary analyses was quite crude and did not take into account other immediate and gradual changes in public policies and health care in the two jurisdictions (Zeka *et al.* 2014). Further extensive analyses should be undertaken to explore in depth influences of fuel poverty, socioeconomic, demography, health care and other important factors on the cold weather-mortality association. Future research should be carried out to explore the impact of the implementation of the winter fuel payments, cold weather payments and fuel allowance on the cold weather-mortality relationship to determine their potential effectiveness at reducing excess winter mortality.

As there is a trend of increasing mean temperatures, the variability in temperature is likely to increase, thus potentially contributing to increased frequency of weather extremes (Ebi and Mills 2012; Field *et al.* 2014; Kinney *et al.* 2012; Staddon *et al.* 2014). Further research should explore the impact of cold spells in addition to the current cold weather-mortality relationship over an extended study period to include the most recently available mortality and weather data and this should be modelled into the

future using the different predicted climate models for both jurisdictions to assess the impact of climate change on excess winter mortality. Future research should also consider the geographical variations in the current cold weather-mortality associations as well as the future predicted relationships.

6.0 References

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7.0 FIGURES AND TABLES

Figure 1. A comparison of the annual mortality rates (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2006.

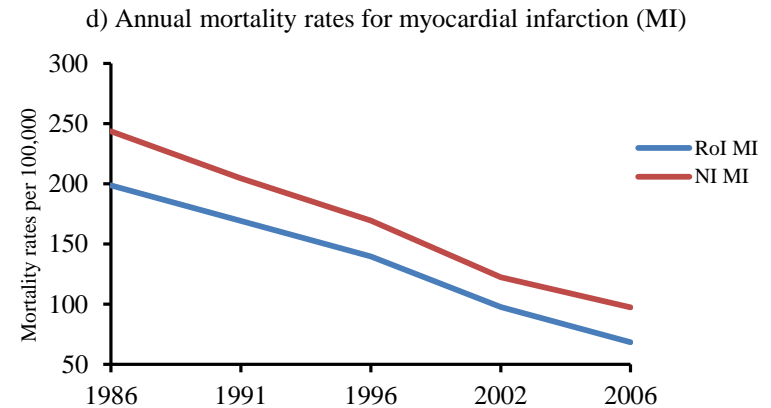
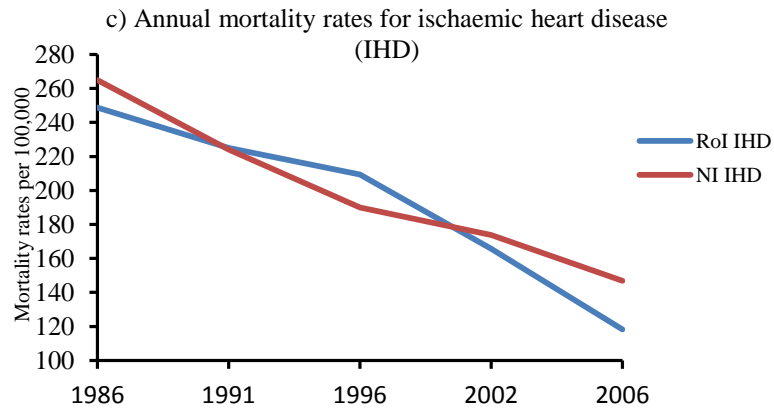
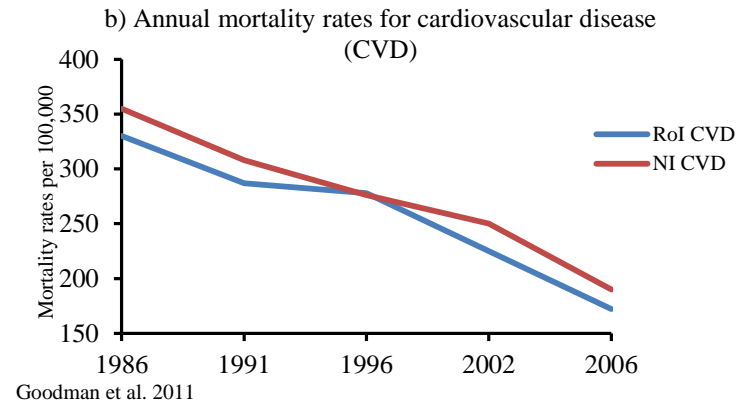
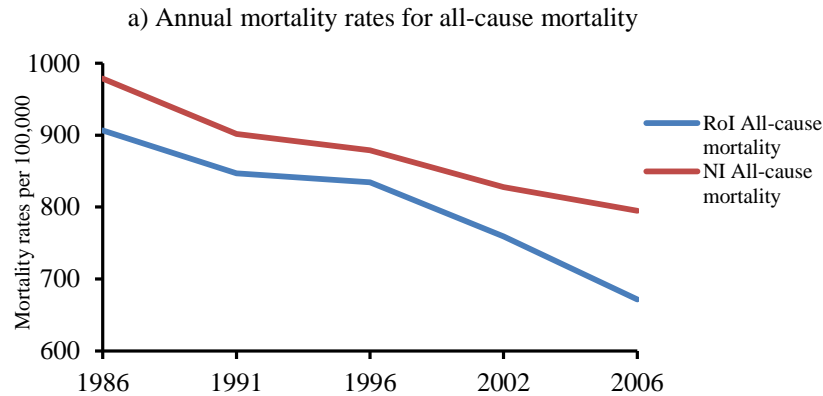


Figure 2. A comparison of the annual mortality rates (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2006.

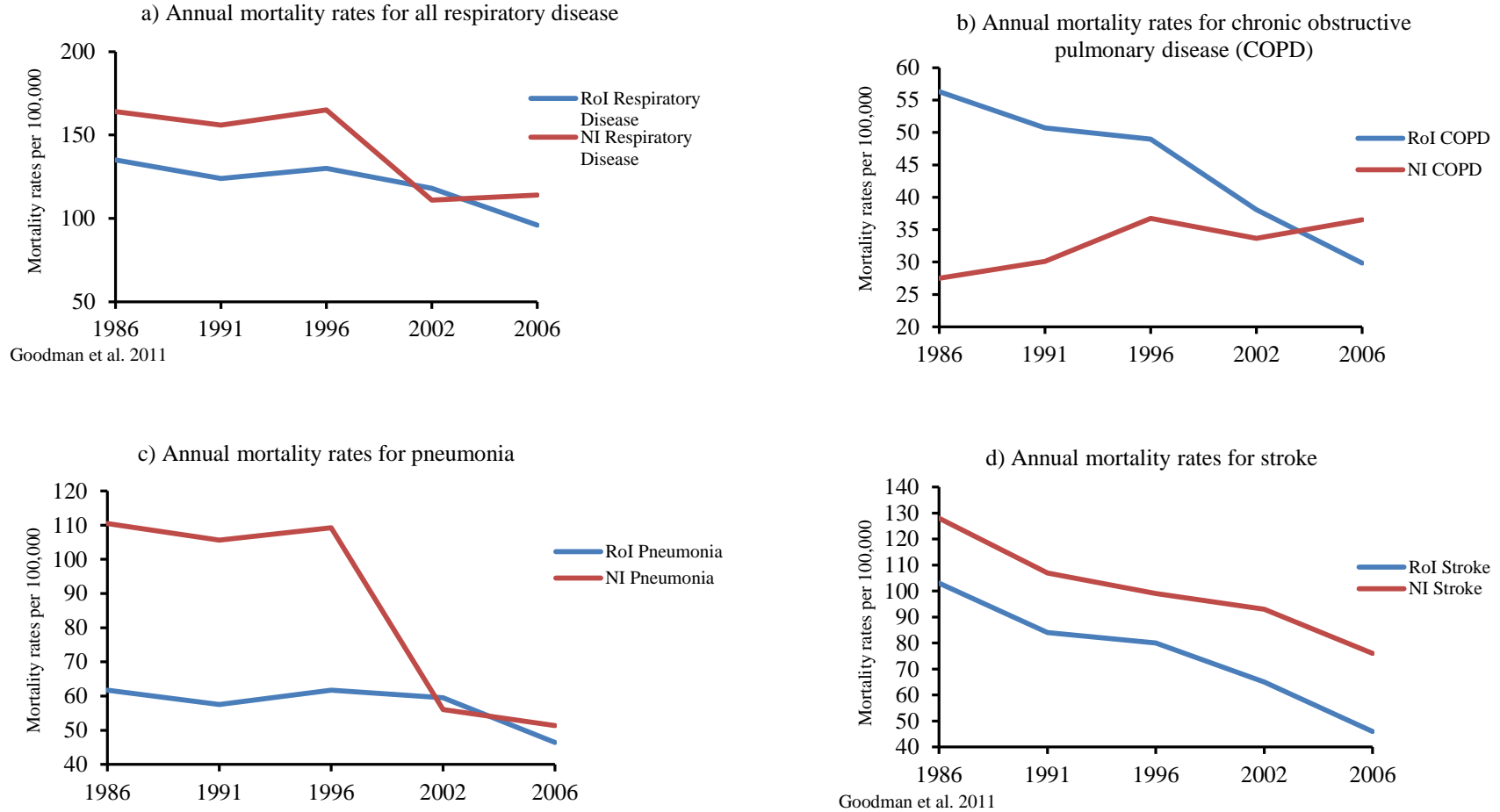


Figure 3. A comparison of the summer and winter mortality rates for all-cause mortality (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

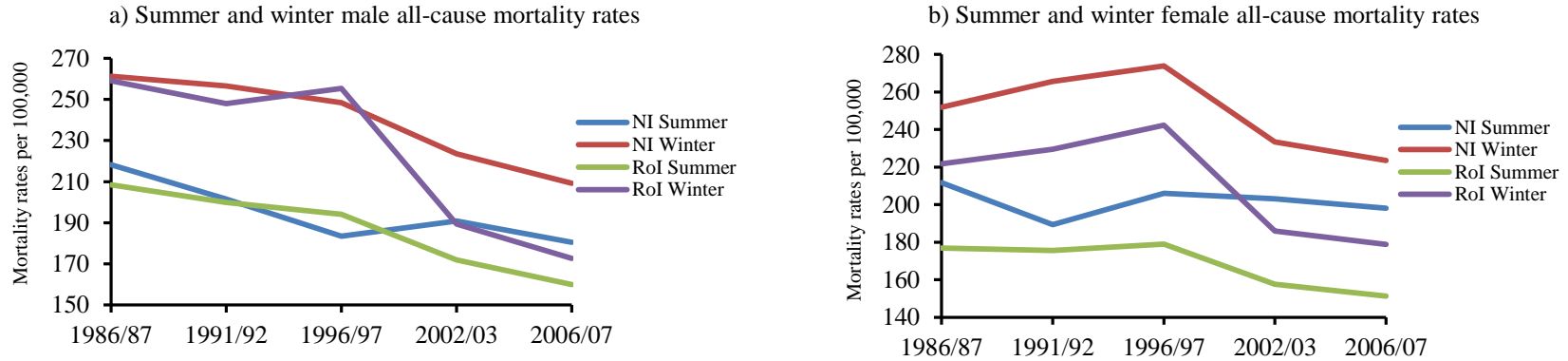


Figure 4. A comparison of the summer and winter mortality rates for cardiovascular disease (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

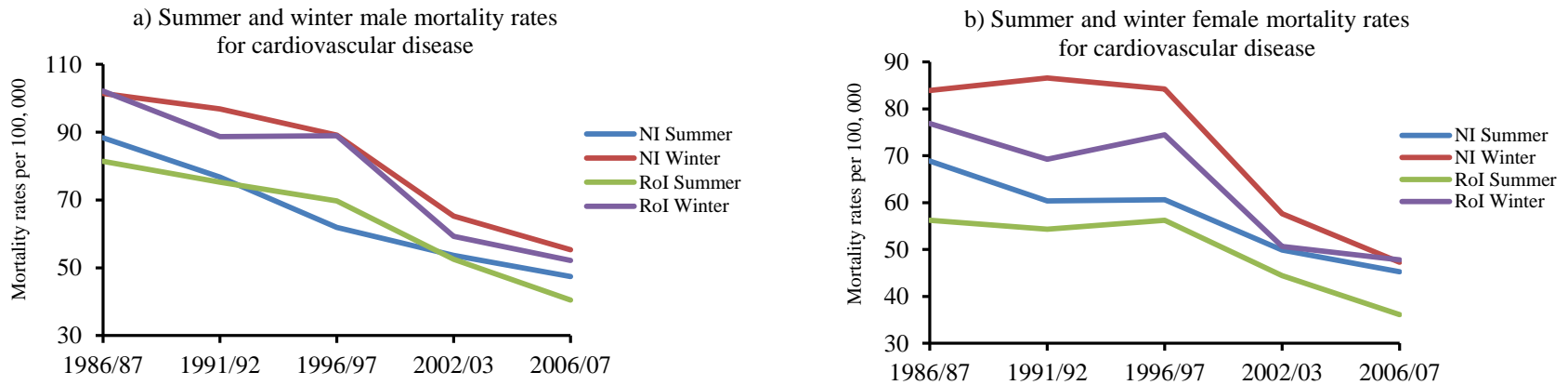


Figure 5. A comparison of the summer and winter mortality rates for ischaemic heart disease (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

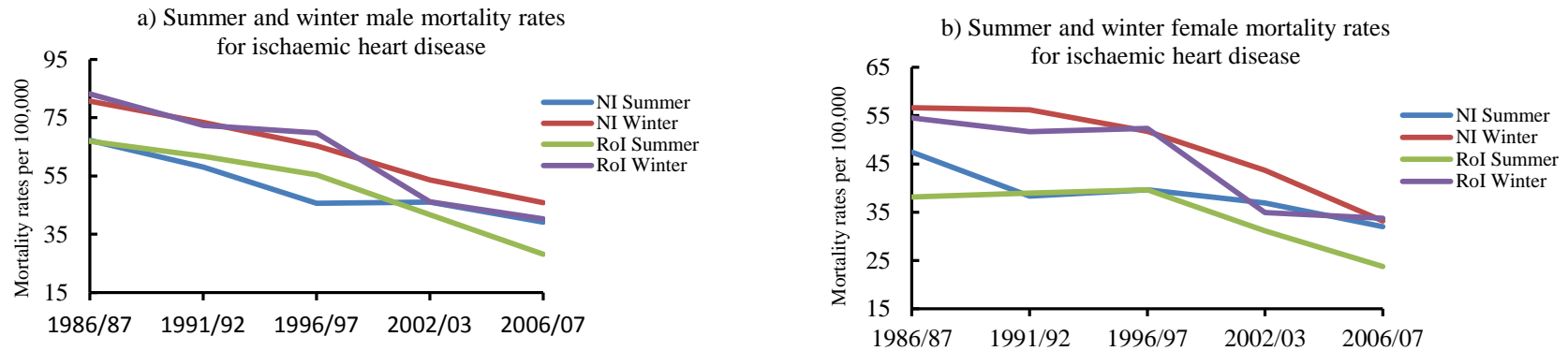


Figure 6. A comparison of the summer and winter mortality rates for myocardial infarction (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

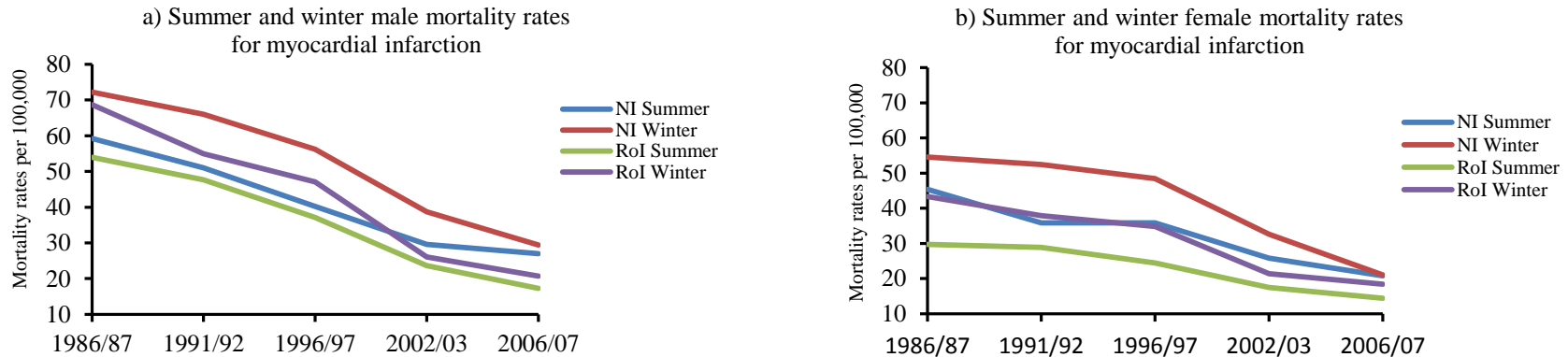


Figure 7. A comparison of the summer and winter mortality rates for all respiratory disease (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

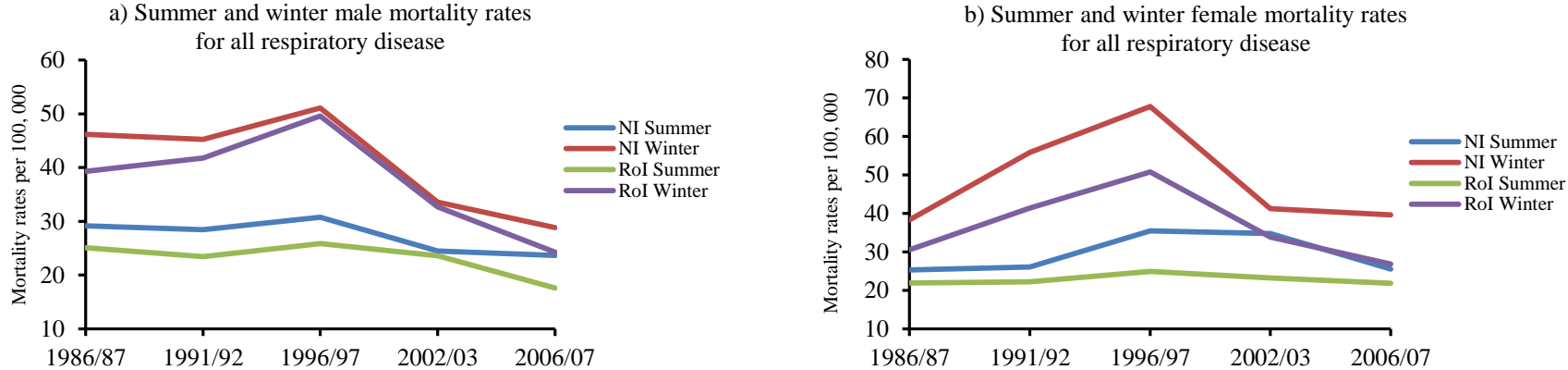


Figure 8. A comparison of the summer and winter mortality rates for pneumonia (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

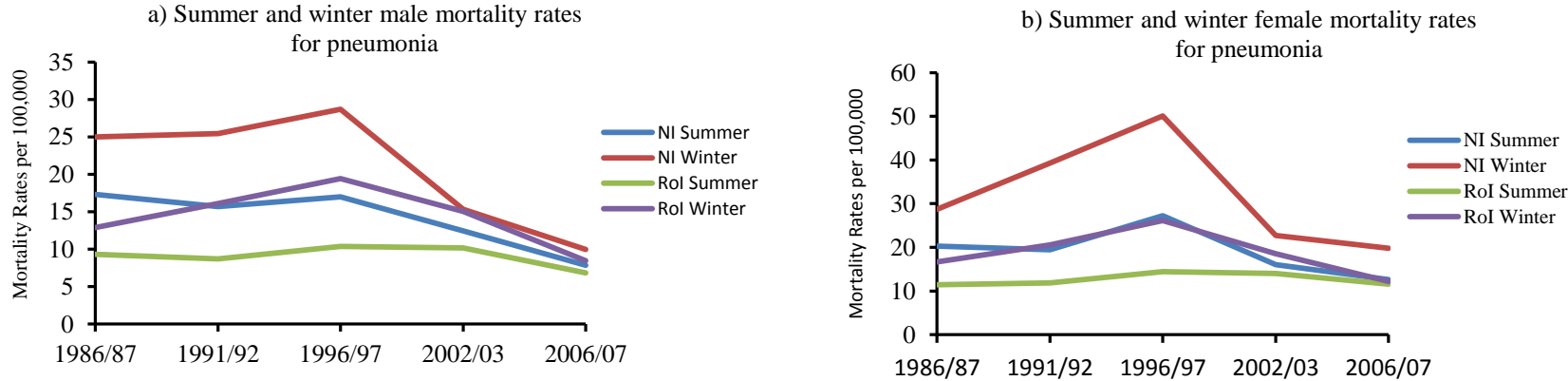


Figure 9. A comparison of the summer and winter mortality rates for chronic obstructive pulmonary disease (COPD) (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

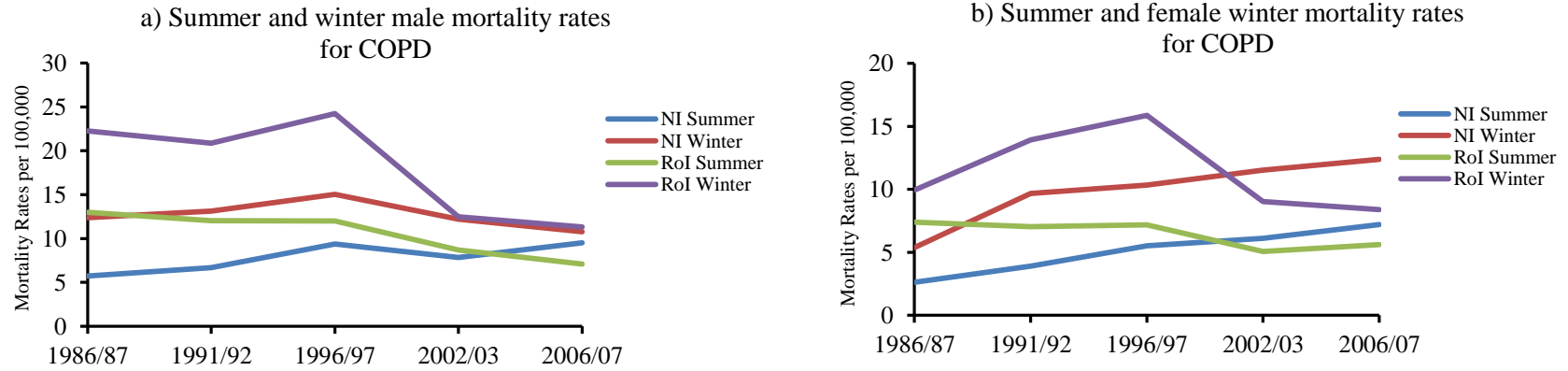


Figure 10. A comparison of the summer and winter mortality rates for stroke (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

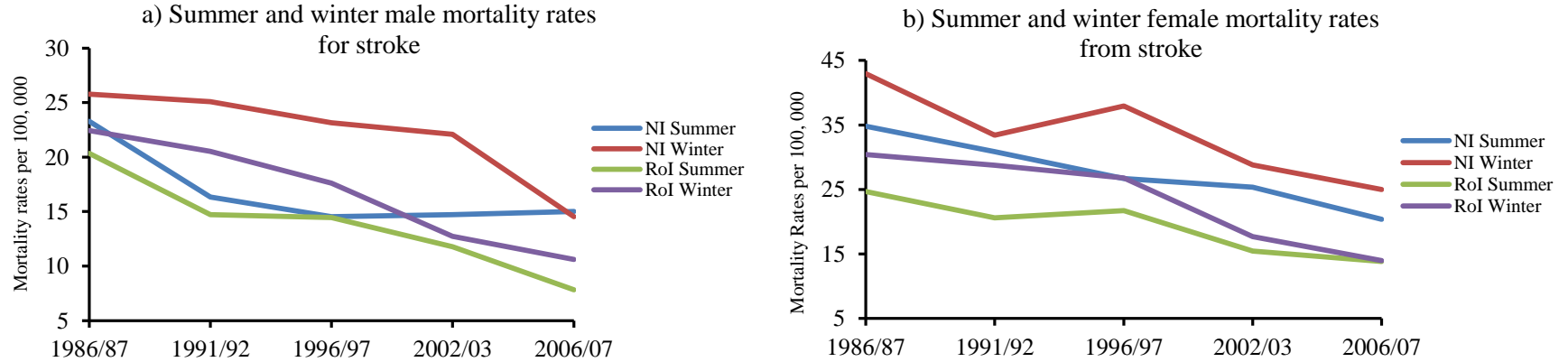


Figure 11. A comparison of the mortality rates for all-cause mortality, cardiovascular disease, ischaemic heart disease and myocardial infarction in the population during the winter months (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

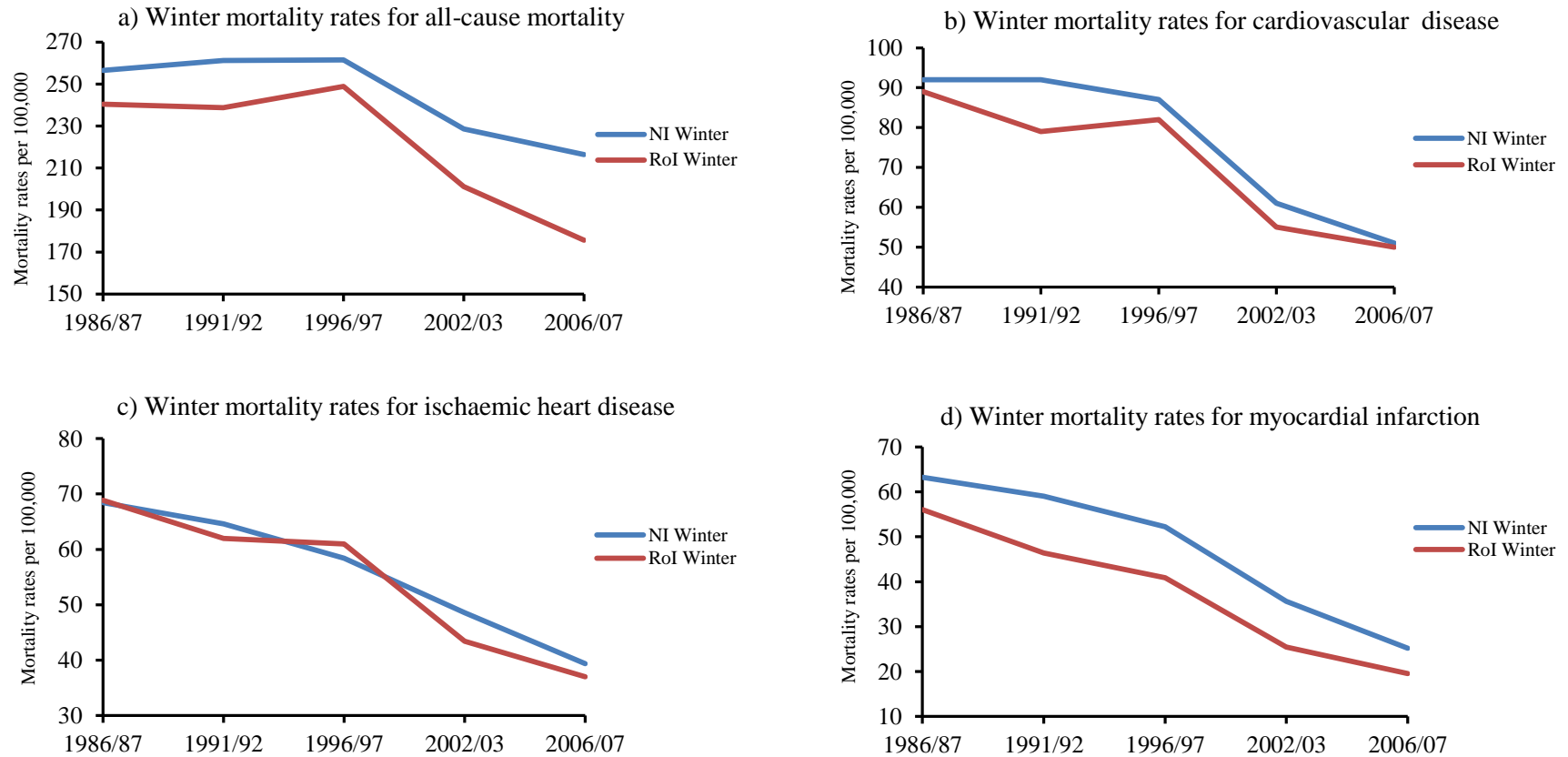
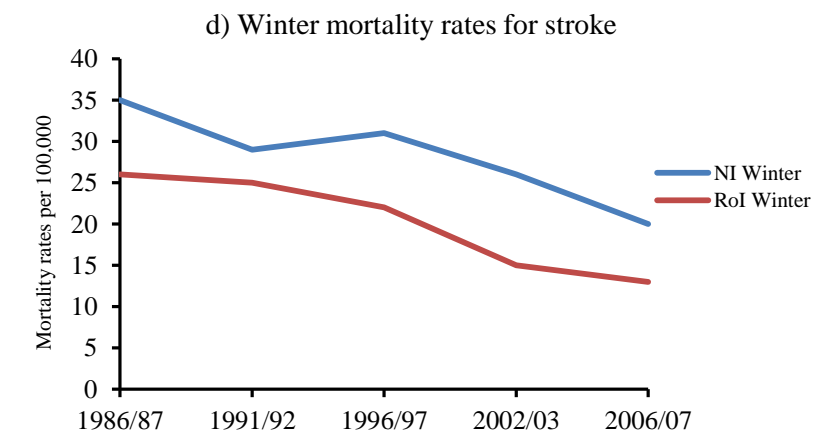
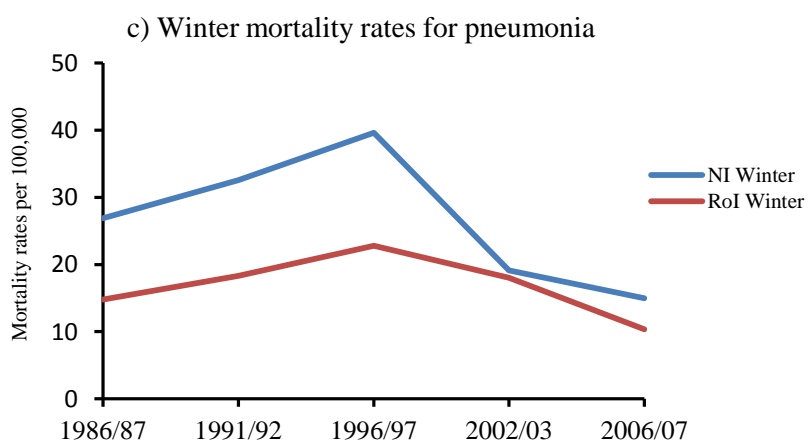
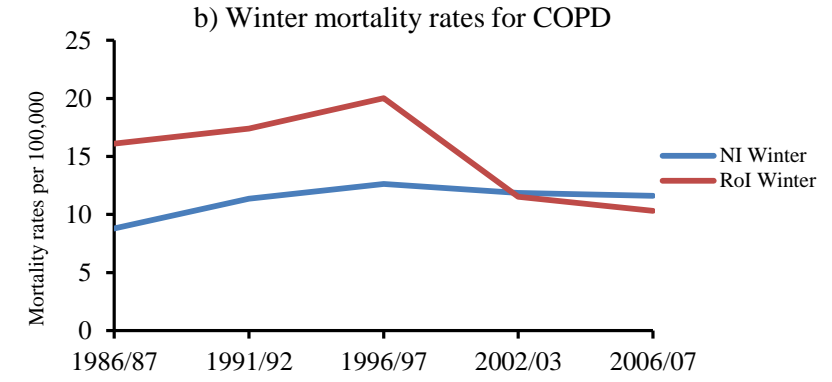
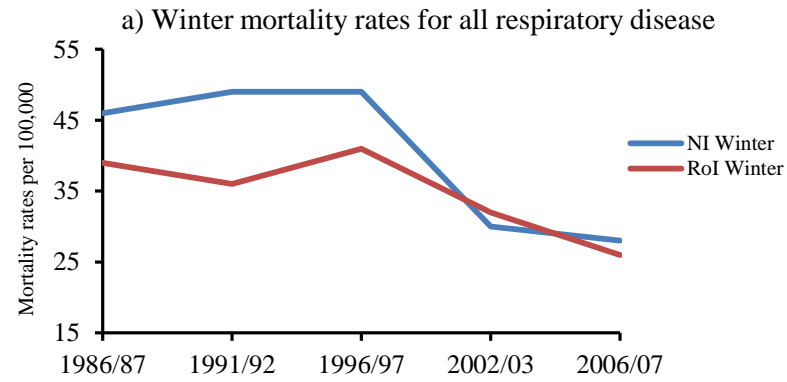


Figure 12. A comparison of the mortality rates for all respiratory disease, COPD, pneumonia and stroke in the population during the winter months (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.



Goodman et al. 2011

Figure 13. A comparison of the winter mortality rates for cardiovascular disease (CVD) amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

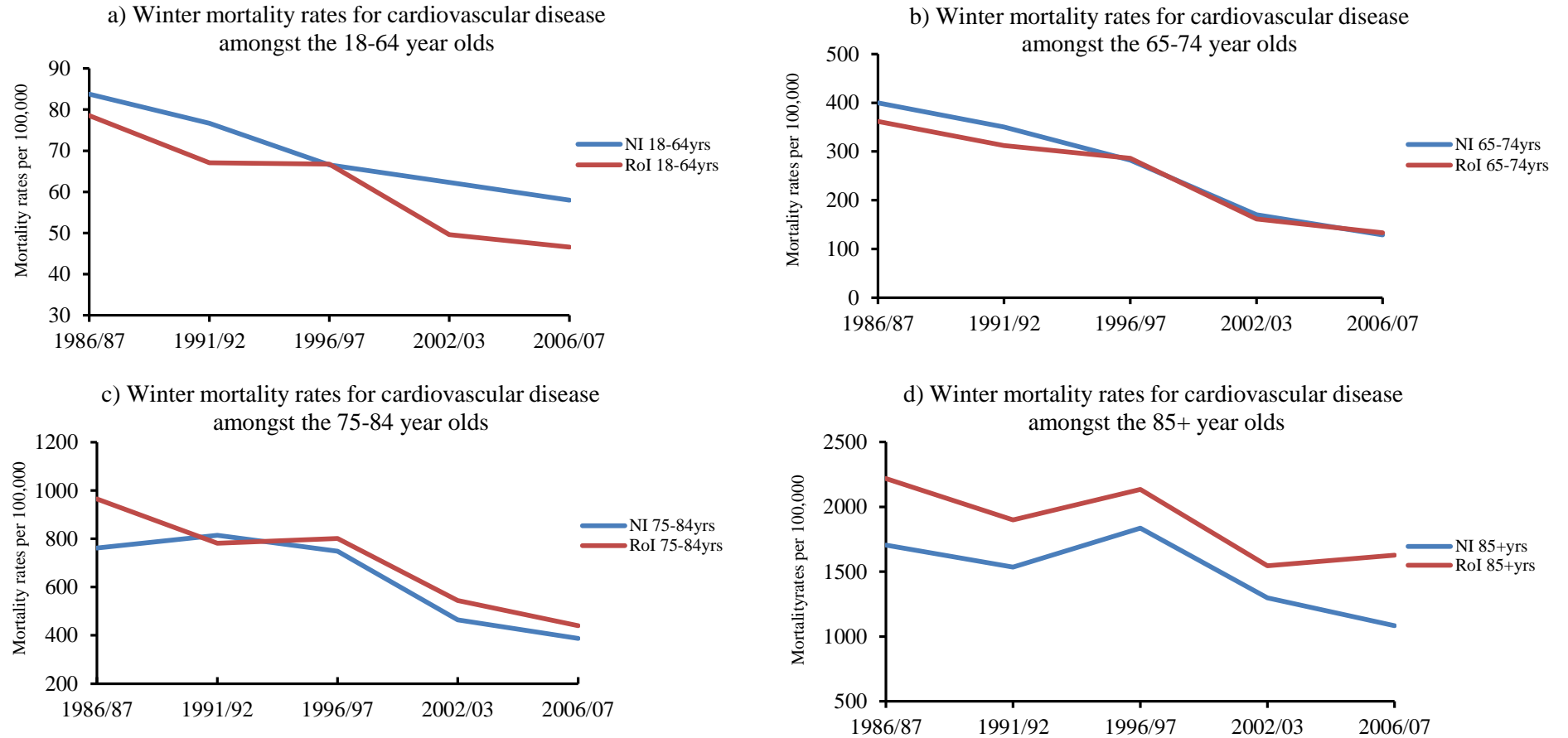


Figure 14. A comparison of the winter mortality rates for ischaemic heart disease (IHD) amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

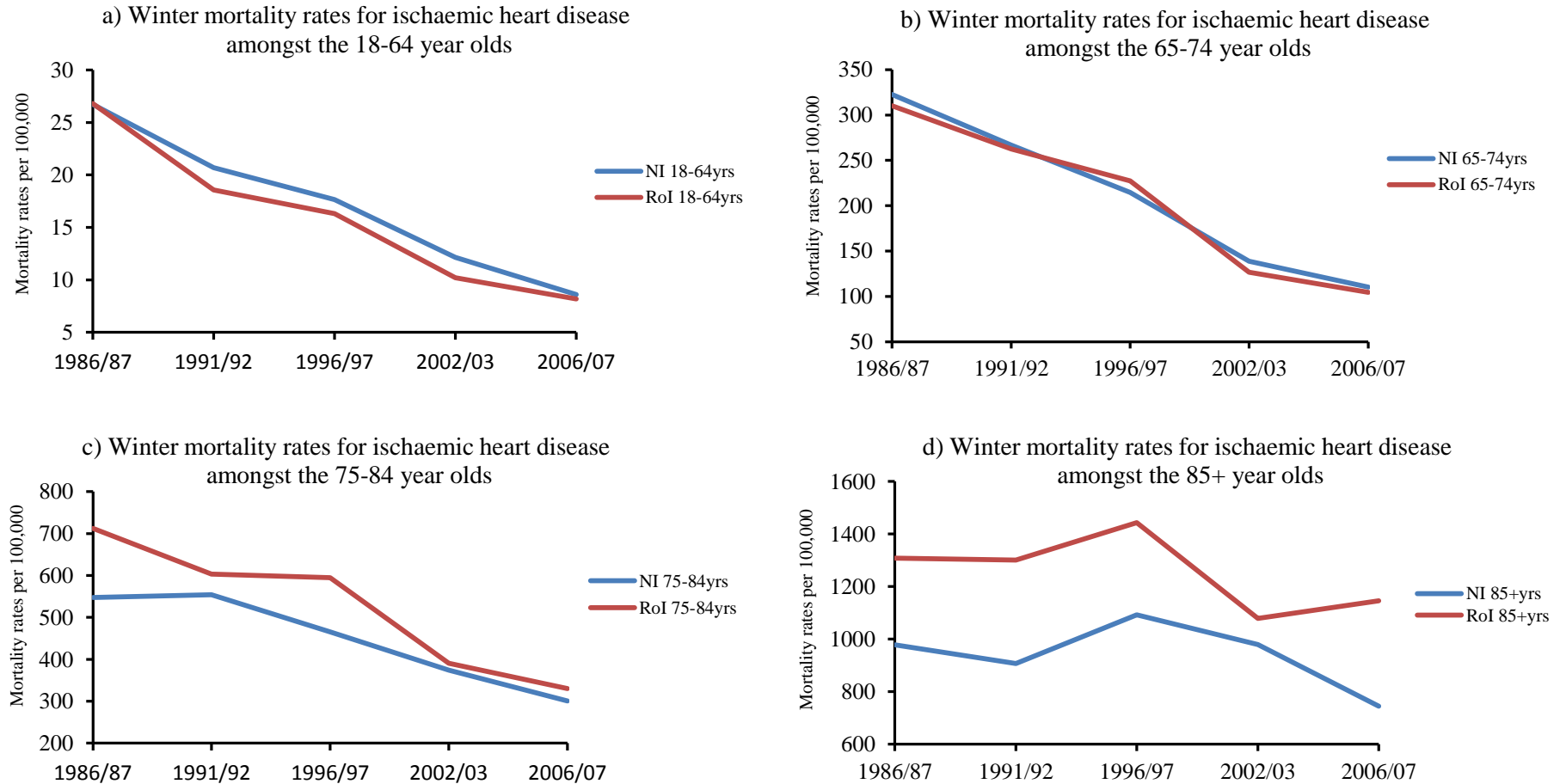


Figure 15. A comparison of the winter mortality rates for myocardial infarction (MI) amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

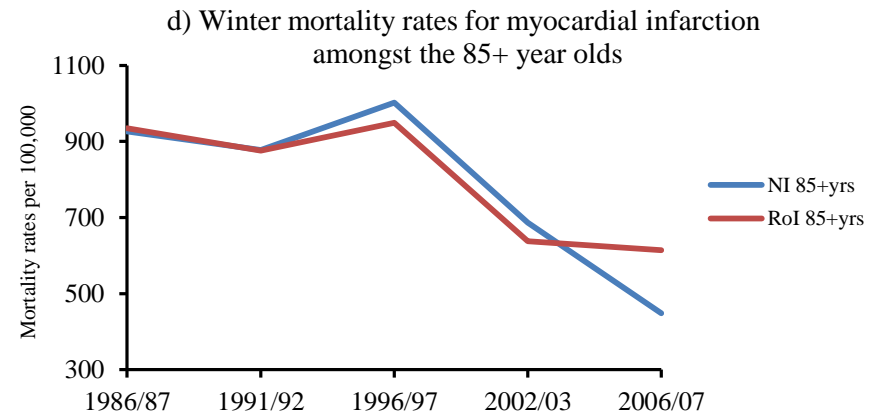
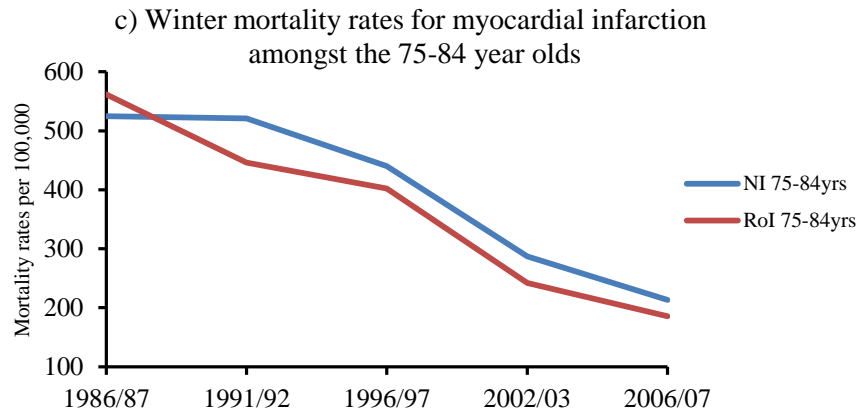
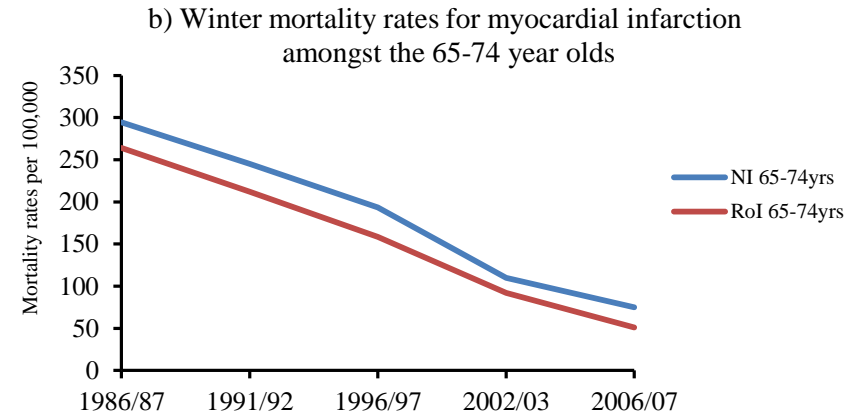
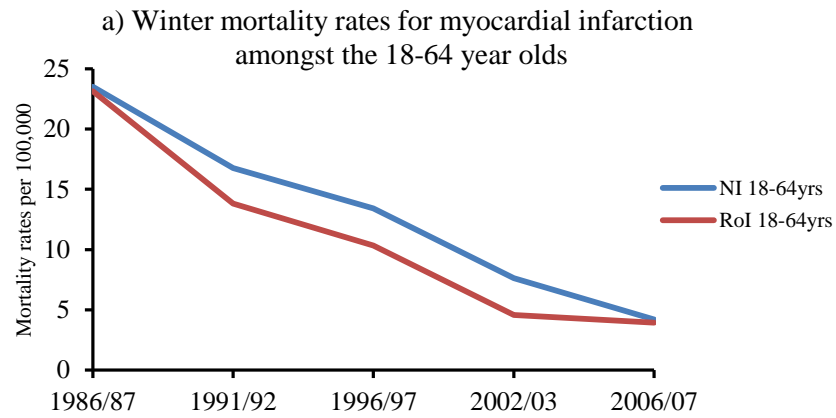


Figure 16. A comparison of the winter mortality rates for all respiratory disease amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

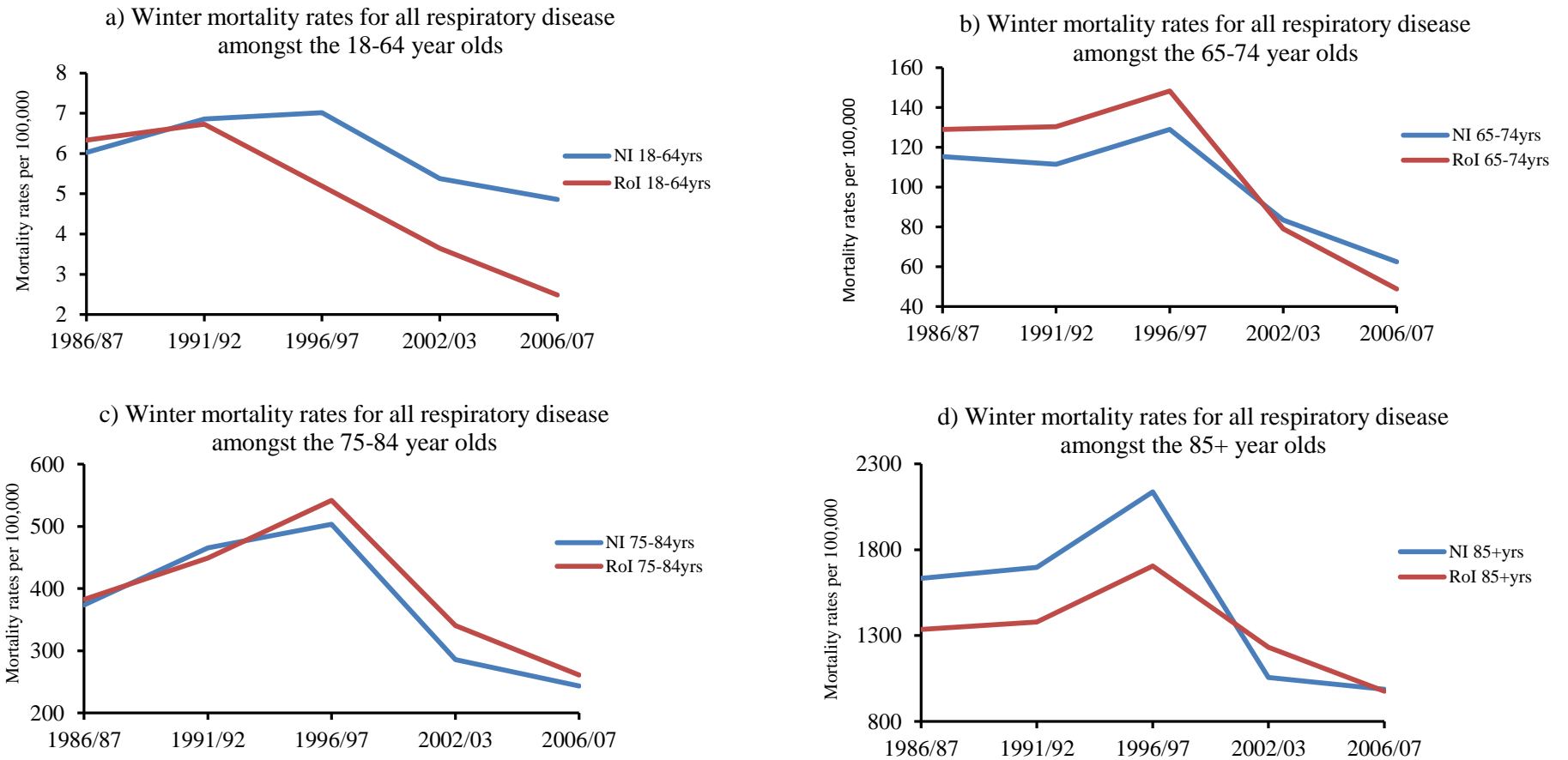


Figure 17. A comparison of the winter mortality rates for chronic pulmonary obstructive disease amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

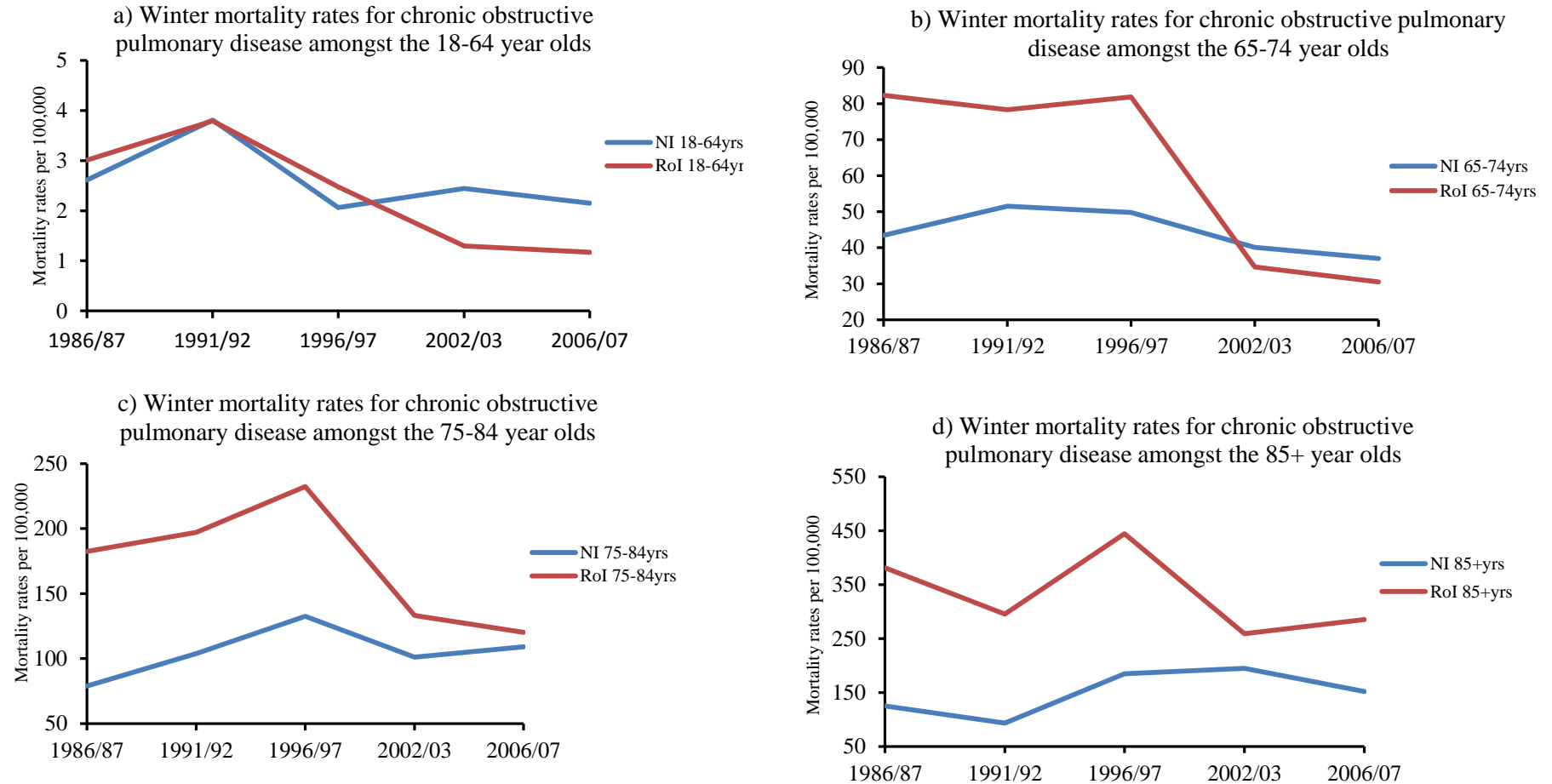


Figure 18. A comparison of the winter mortality rates for pneumonia amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

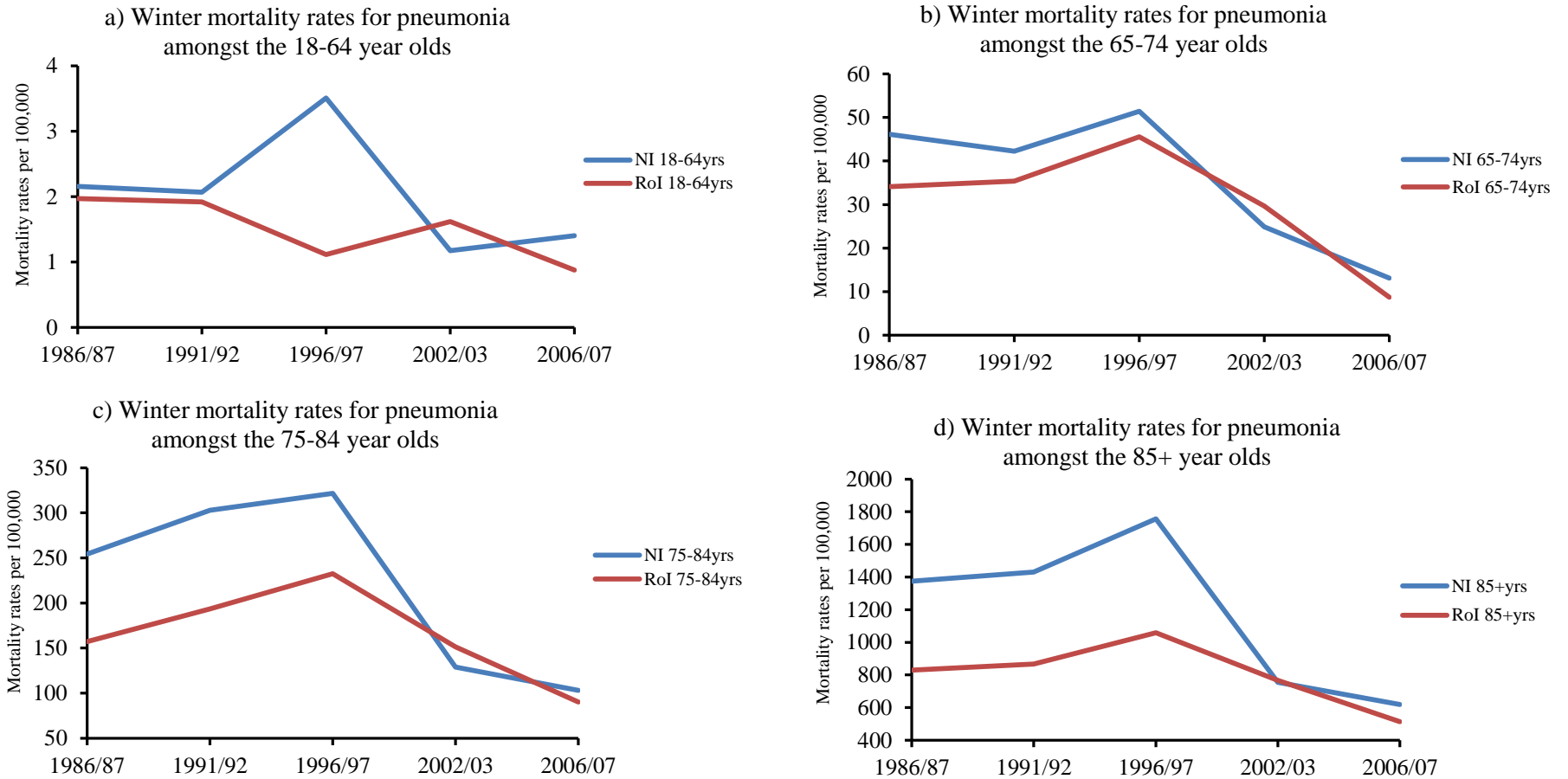
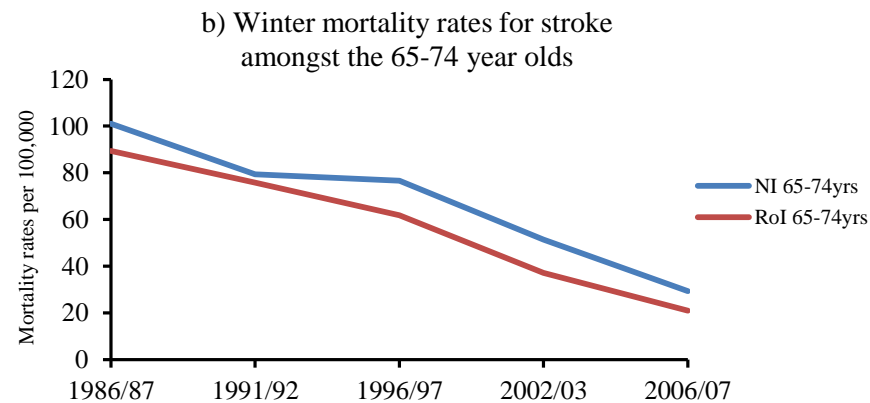
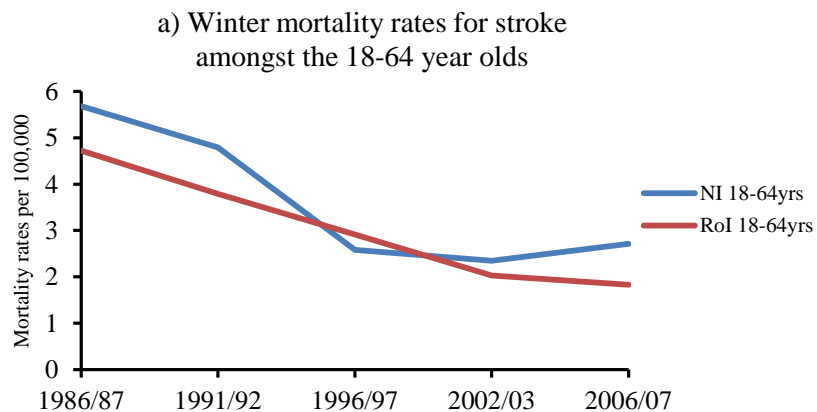
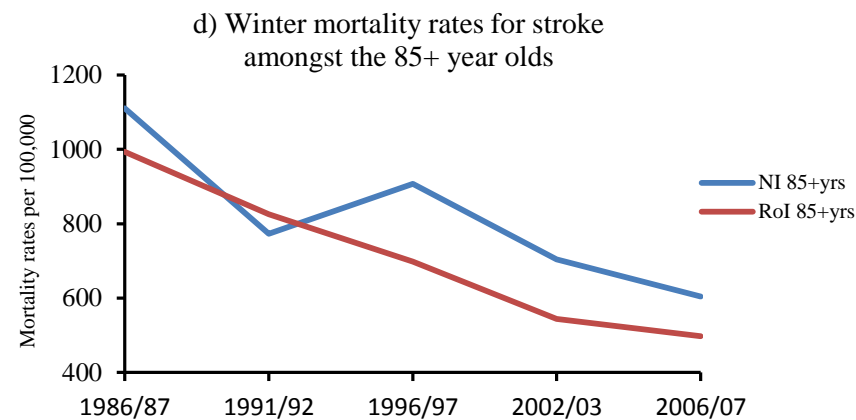
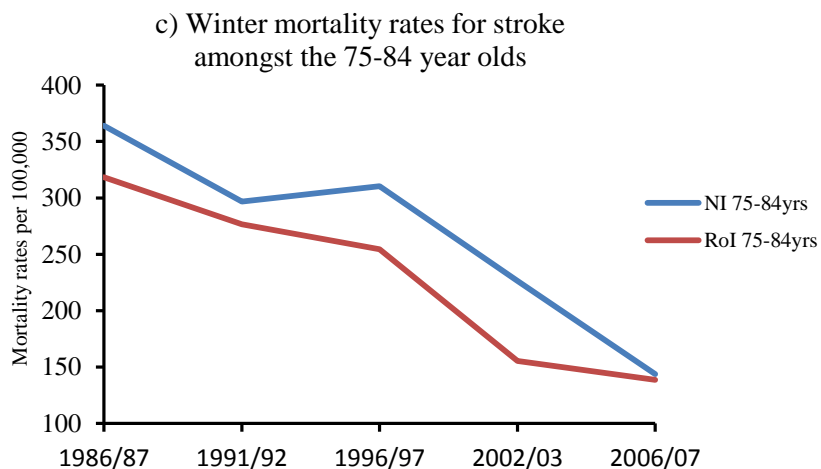


Figure 19. A comparison of the winter mortality rates for stroke amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85 and over year olds in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.



Goodman et al. 2011



Goodman et al. 2011

Figure 20. A comparison of the mortality rates for all-cause mortality, cardiovascular disease, ischaemic heart disease and myocardial infarction in the male population during the cold period (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

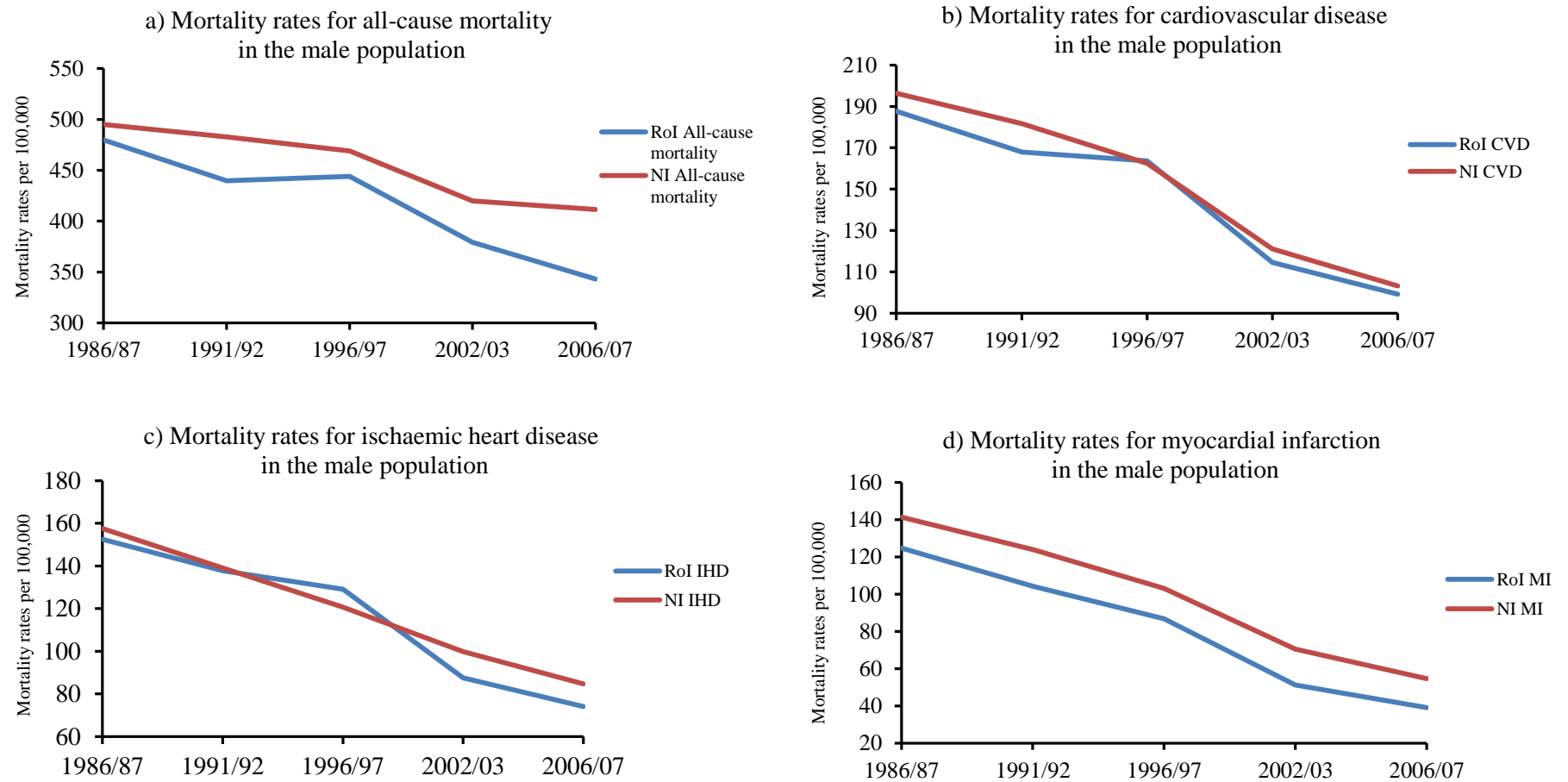


Figure 21. A comparison of the mortality rates for all respiratory disease, chronic obstructive pulmonary disease (COPD), pneumonia and stroke in the male population during the cold period (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

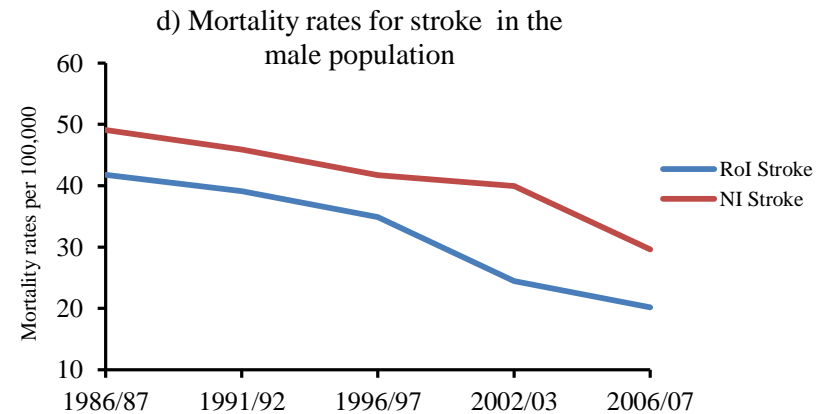
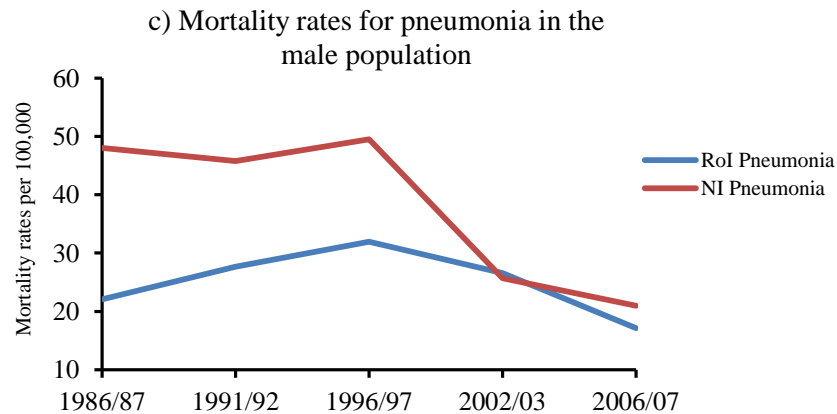
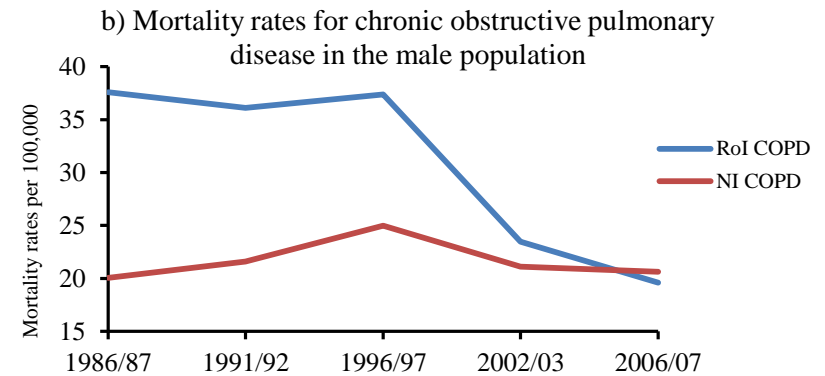
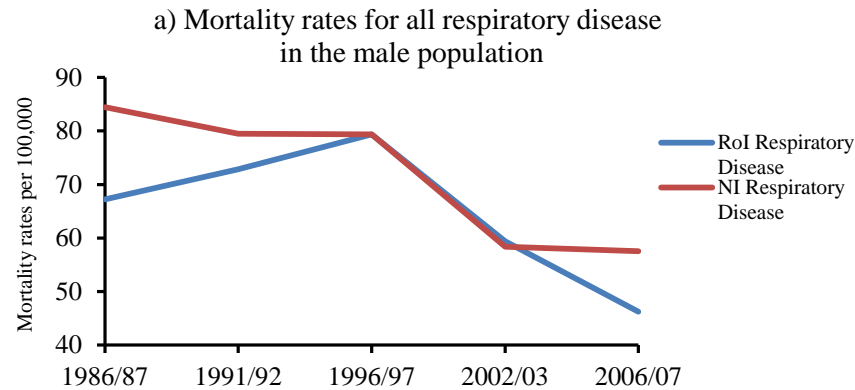


Figure 22. A comparison of the mortality rates for all-cause mortality, cardiovascular disease, ischaemic heart disease and myocardial infarction in the female population during the cold period (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

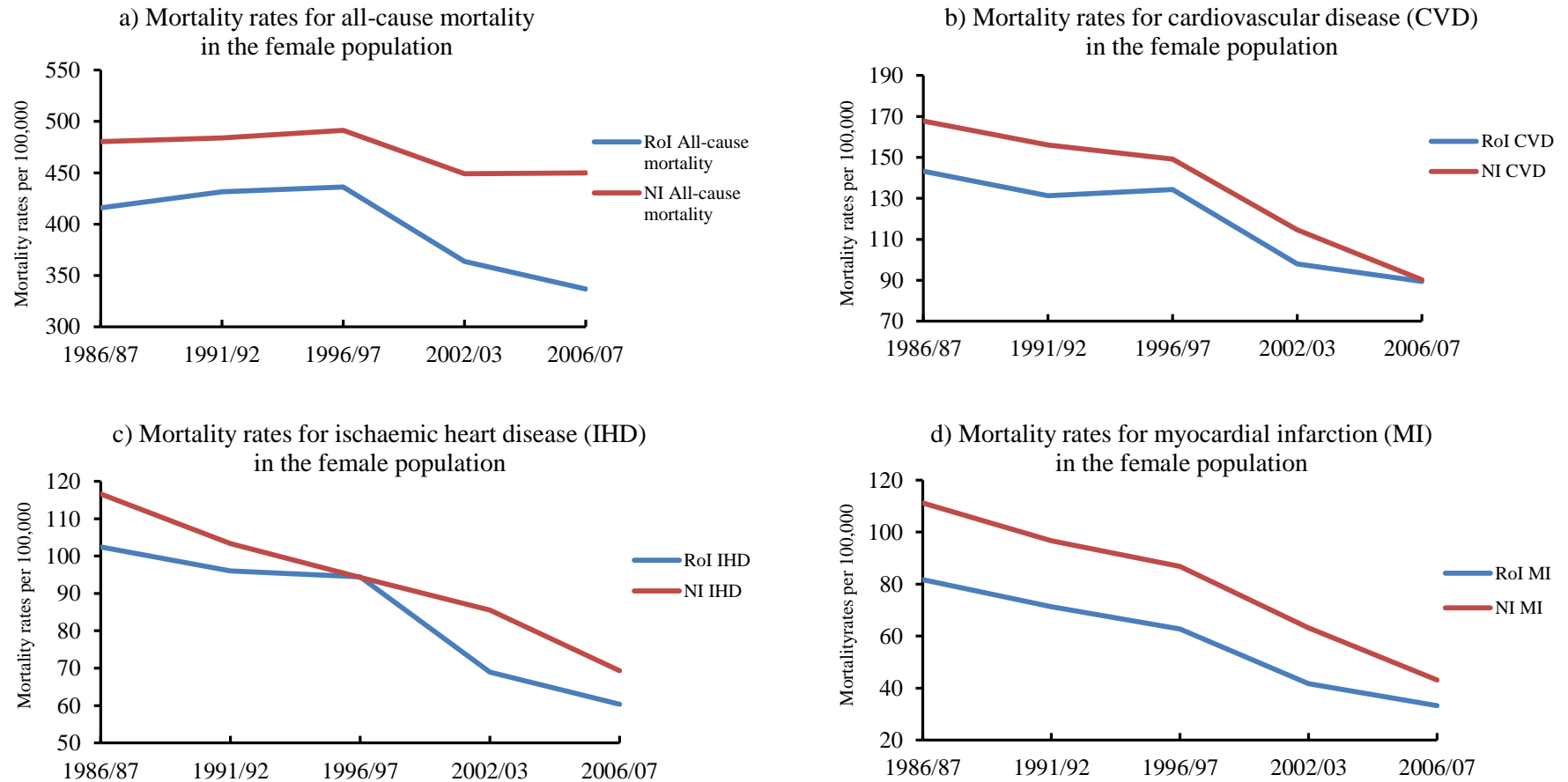


Figure 23. A comparison of the mortality rates for all respiratory disease, chronic obstructive pulmonary disease (COPD), pneumonia and stroke in the female population during the cold period (all ages) in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

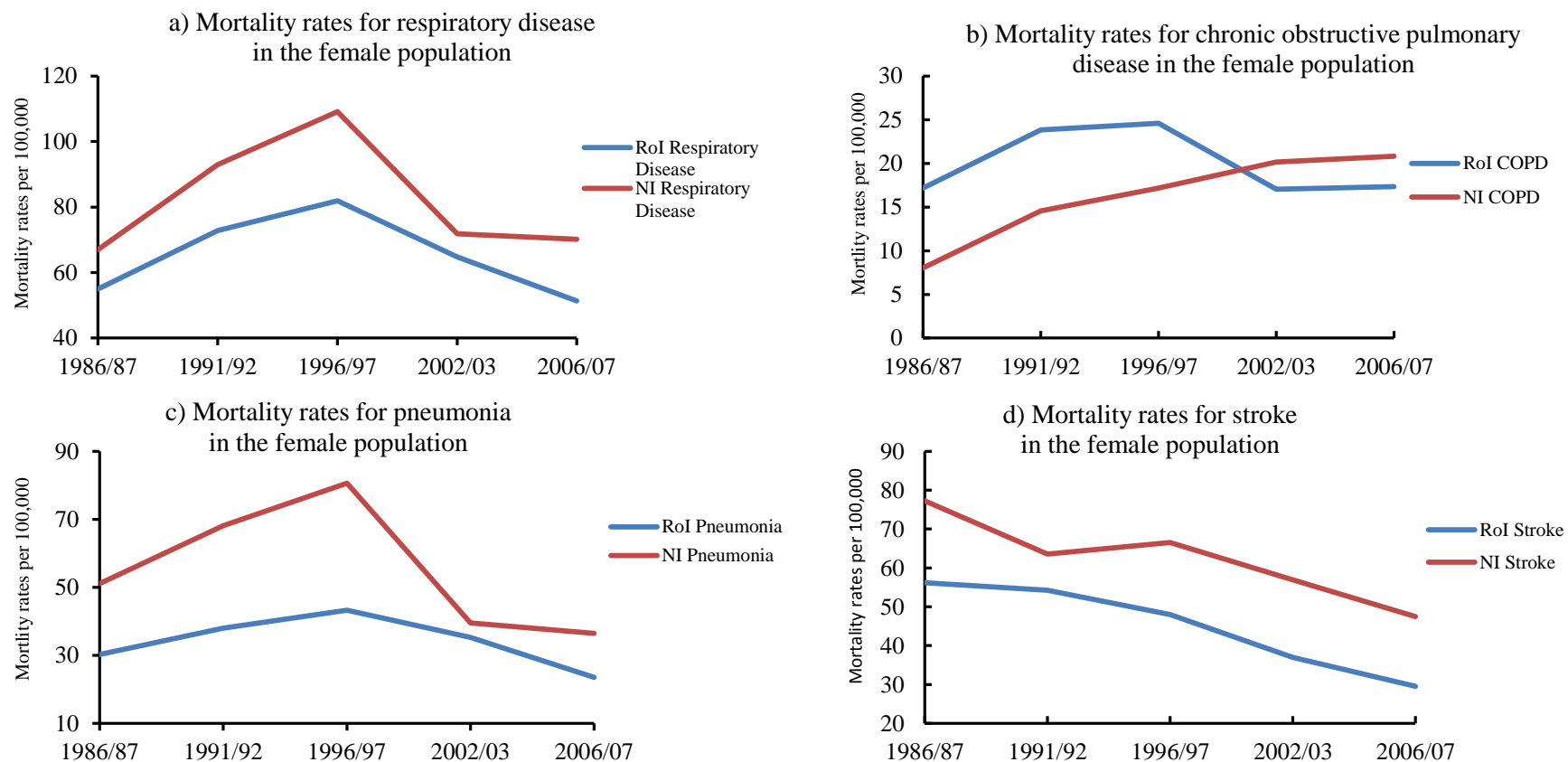


Figure 24. A comparison of the mortality rates for cardiovascular disease amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

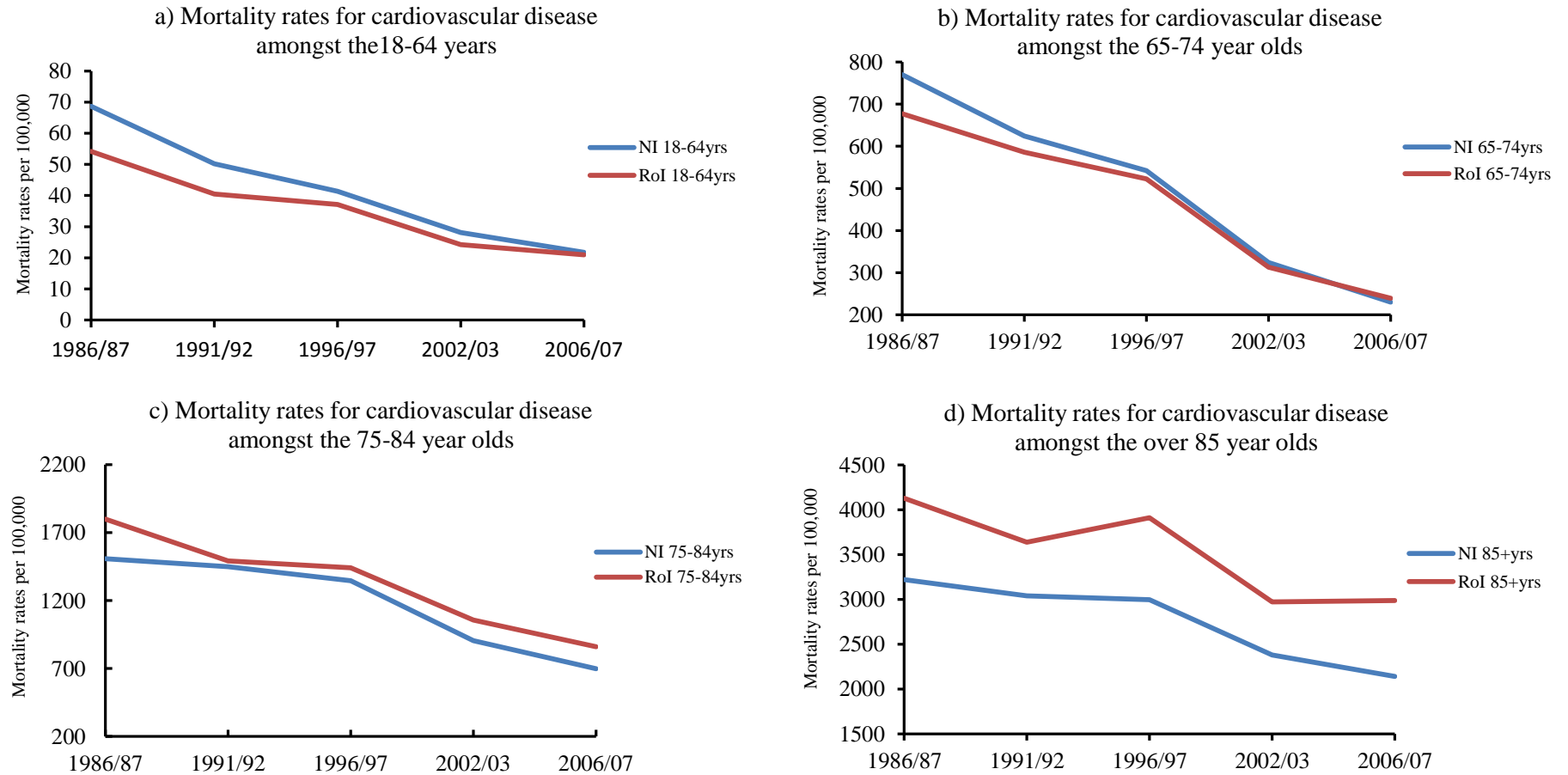


Figure 25. A comparison of the mortality rates for ischaemic heart disease amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

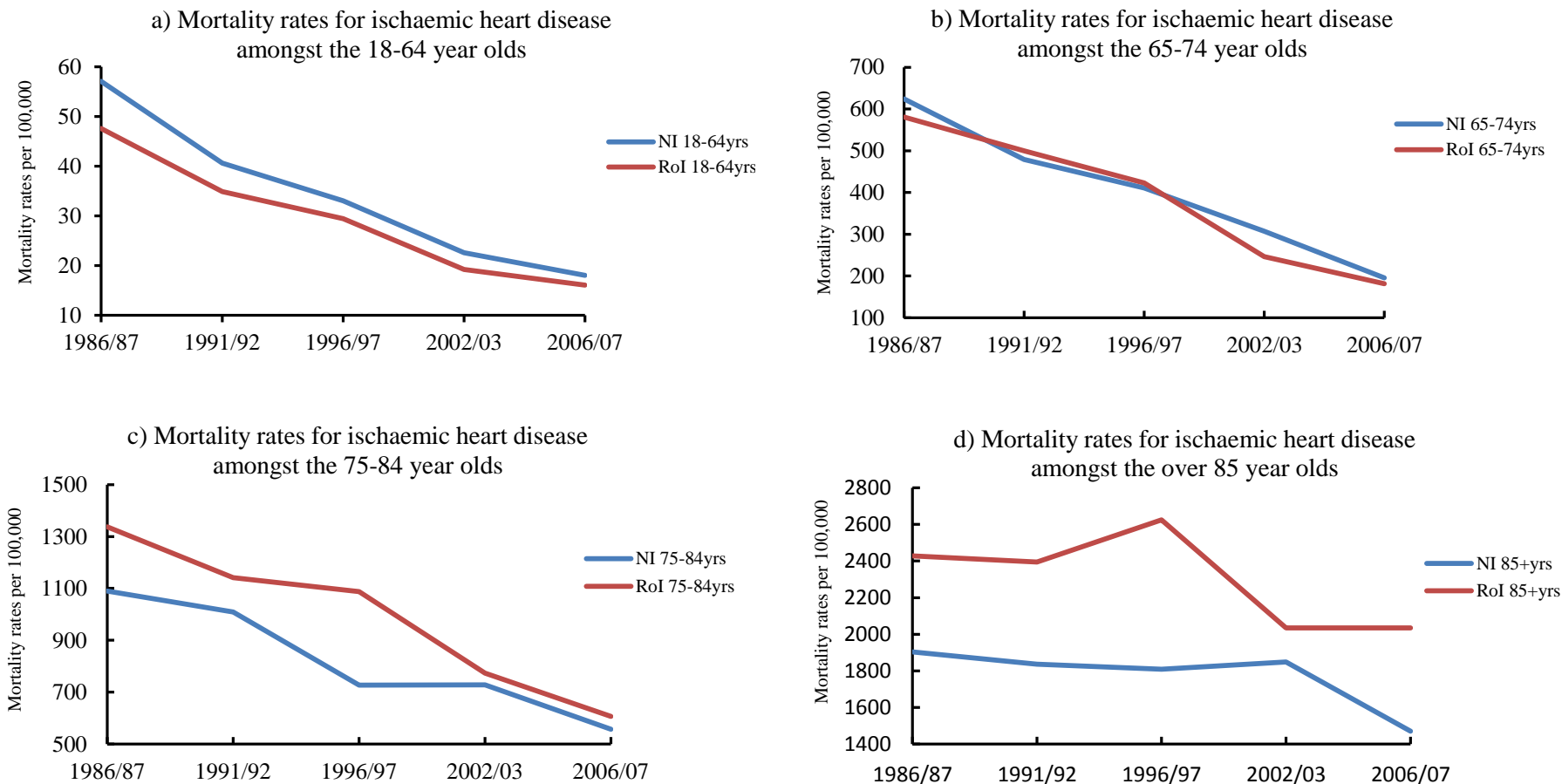


Figure 26. A comparison of the mortality rates for myocardial infarction amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

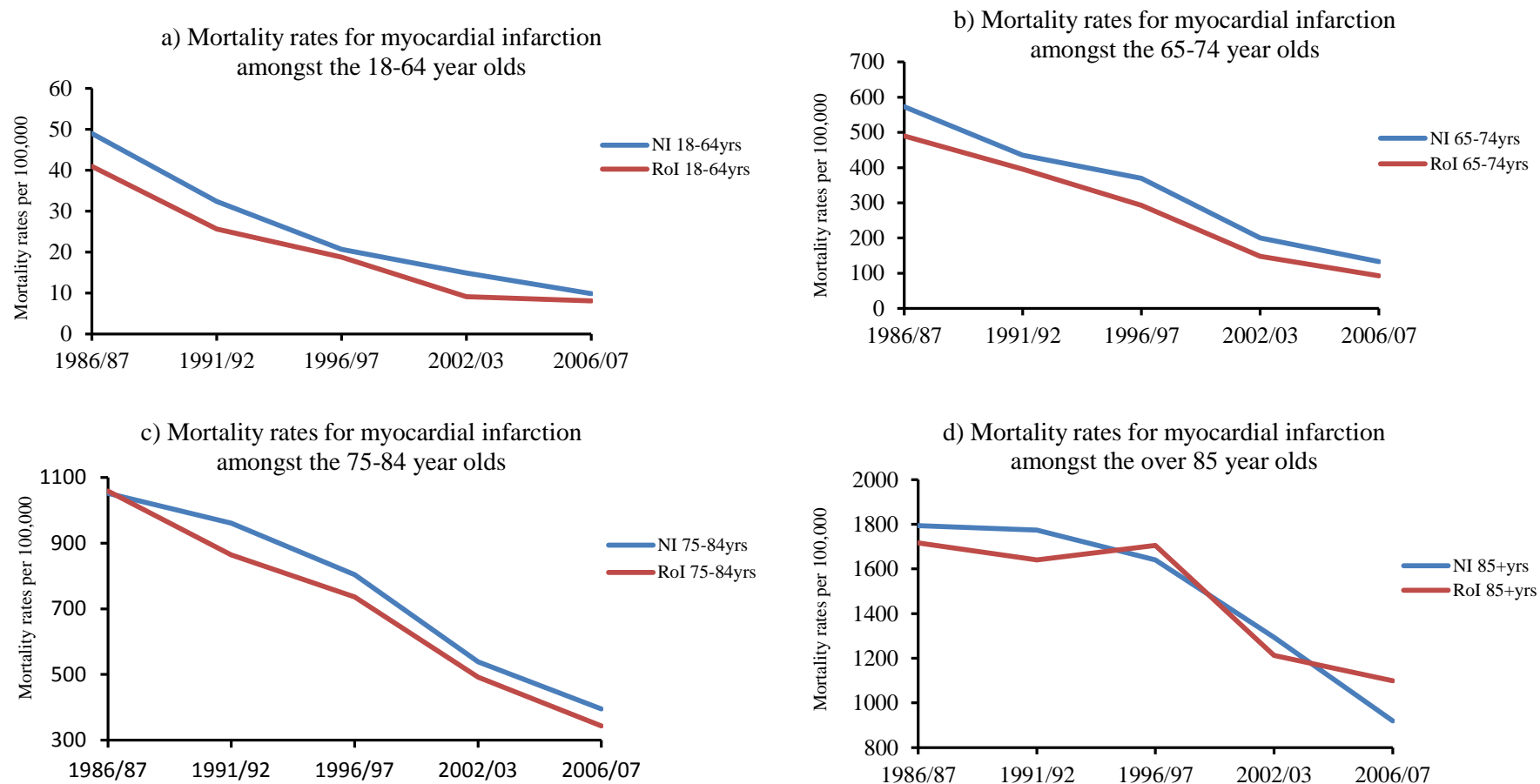


Figure 27. A comparison of the mortality rates for all respiratory diseases amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

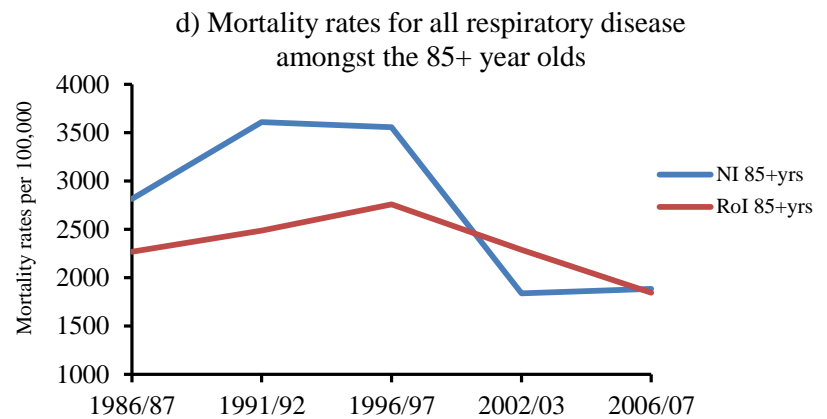
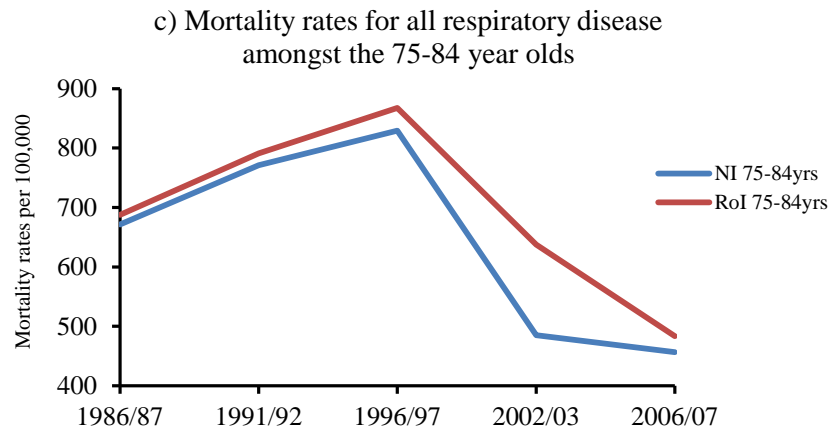
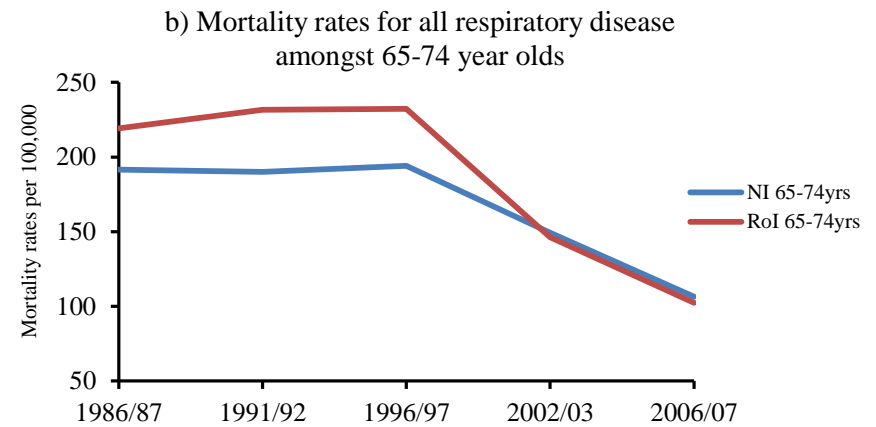
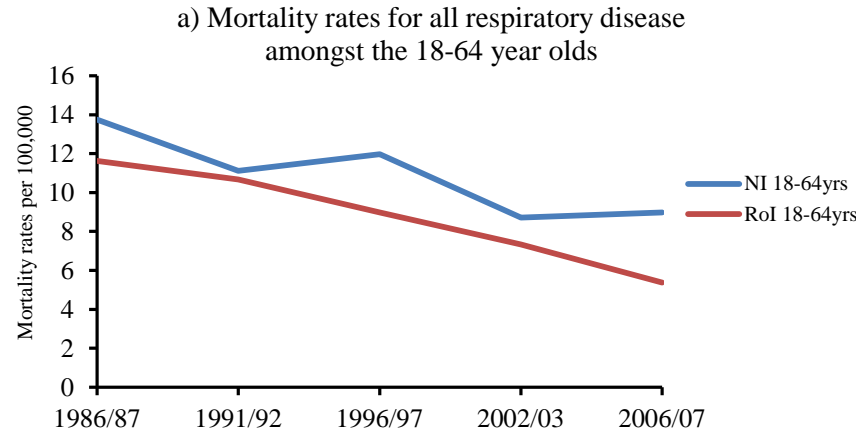


Figure 28. A comparison of the mortality rates for chronic obstructive pulmonary disease (COPD) amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

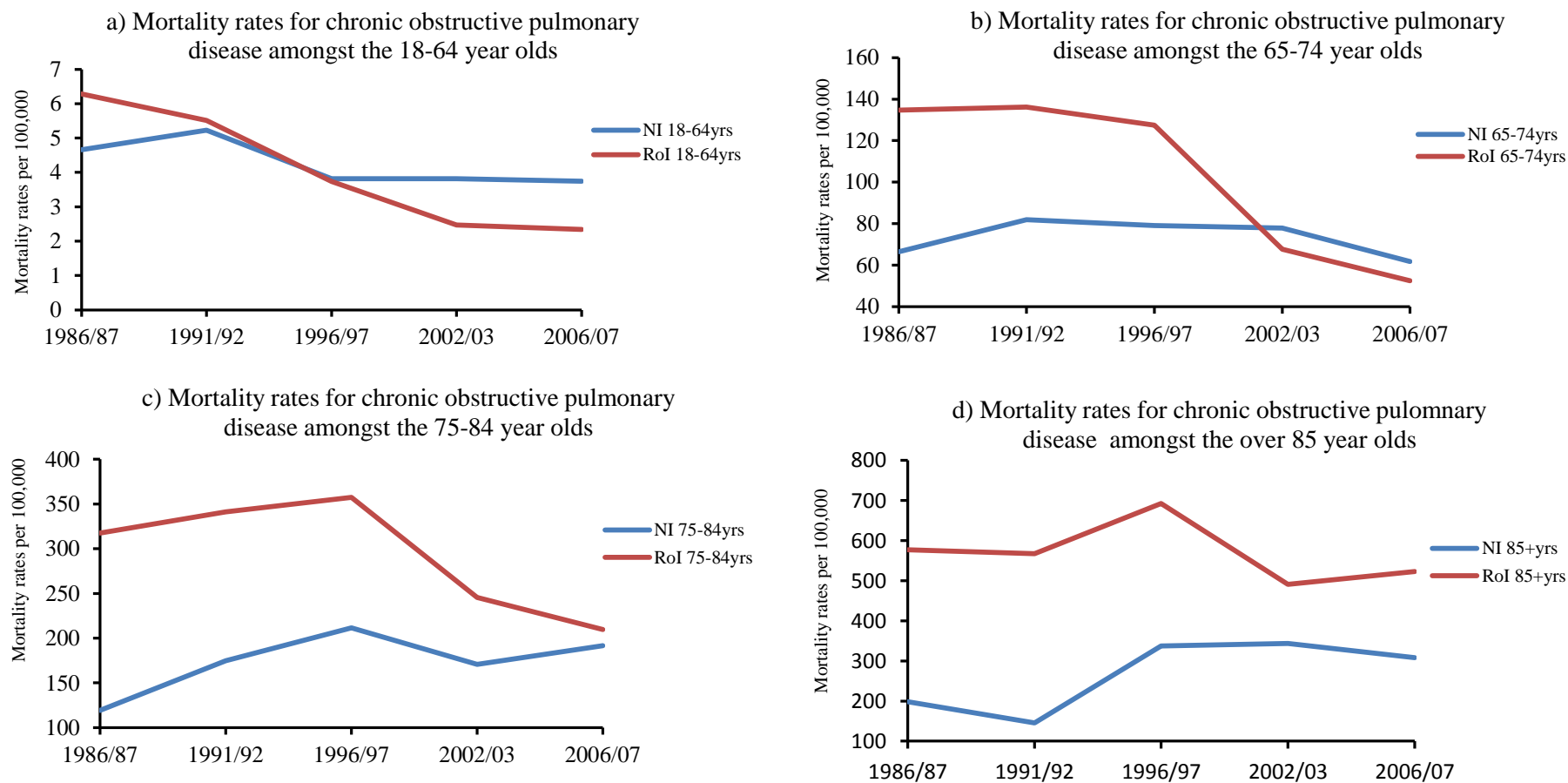


Figure 29. A comparison of the mortality rates for pneumonia amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

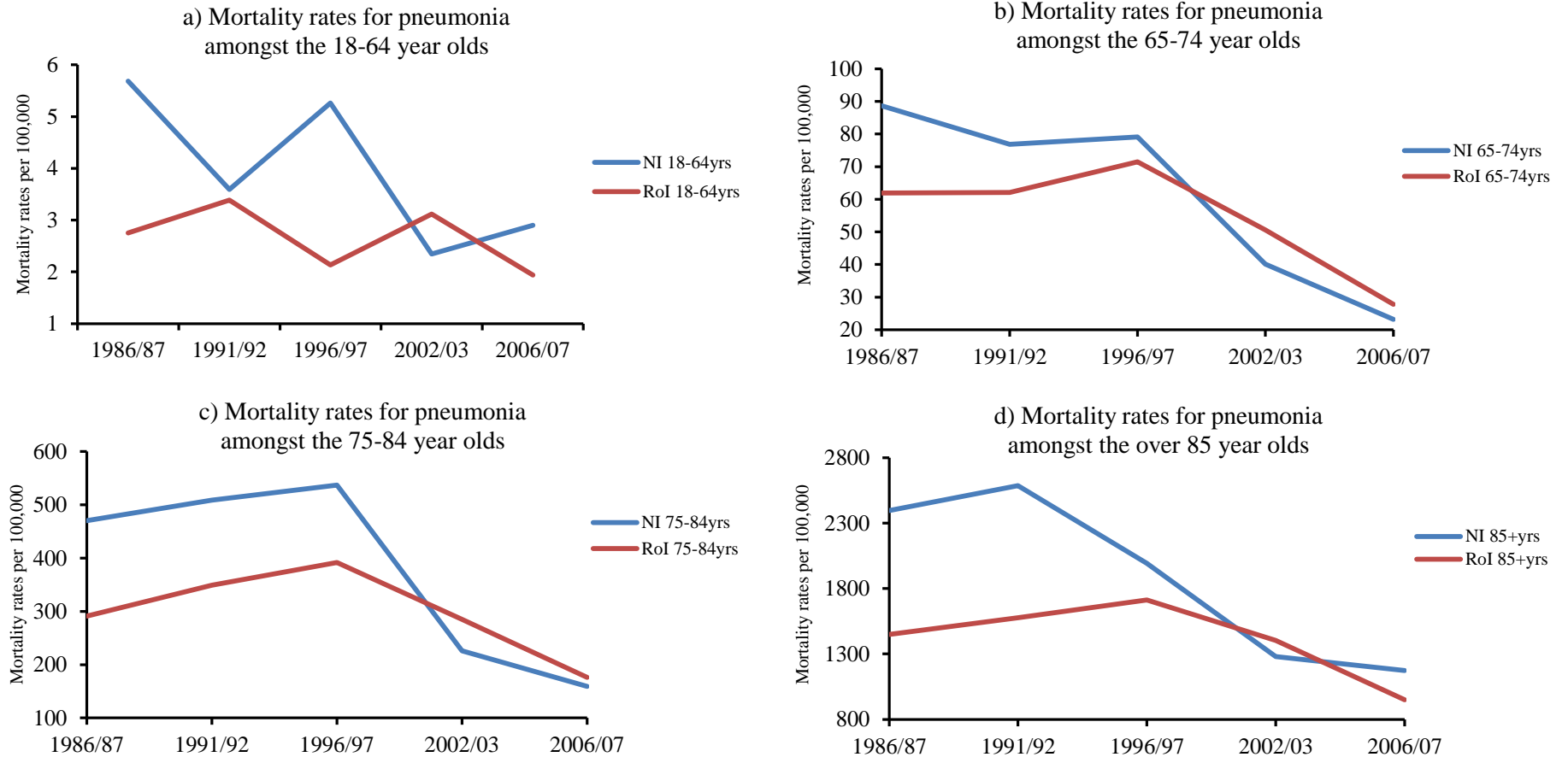


Figure 30. A comparison of the mortality rates for stroke amongst the 18-64 year olds, 65-74 year olds, 75-84 year olds and 85+ year olds during the cold period in the Republic of Ireland (RoI) and Northern Ireland (NI), 1986-2007.

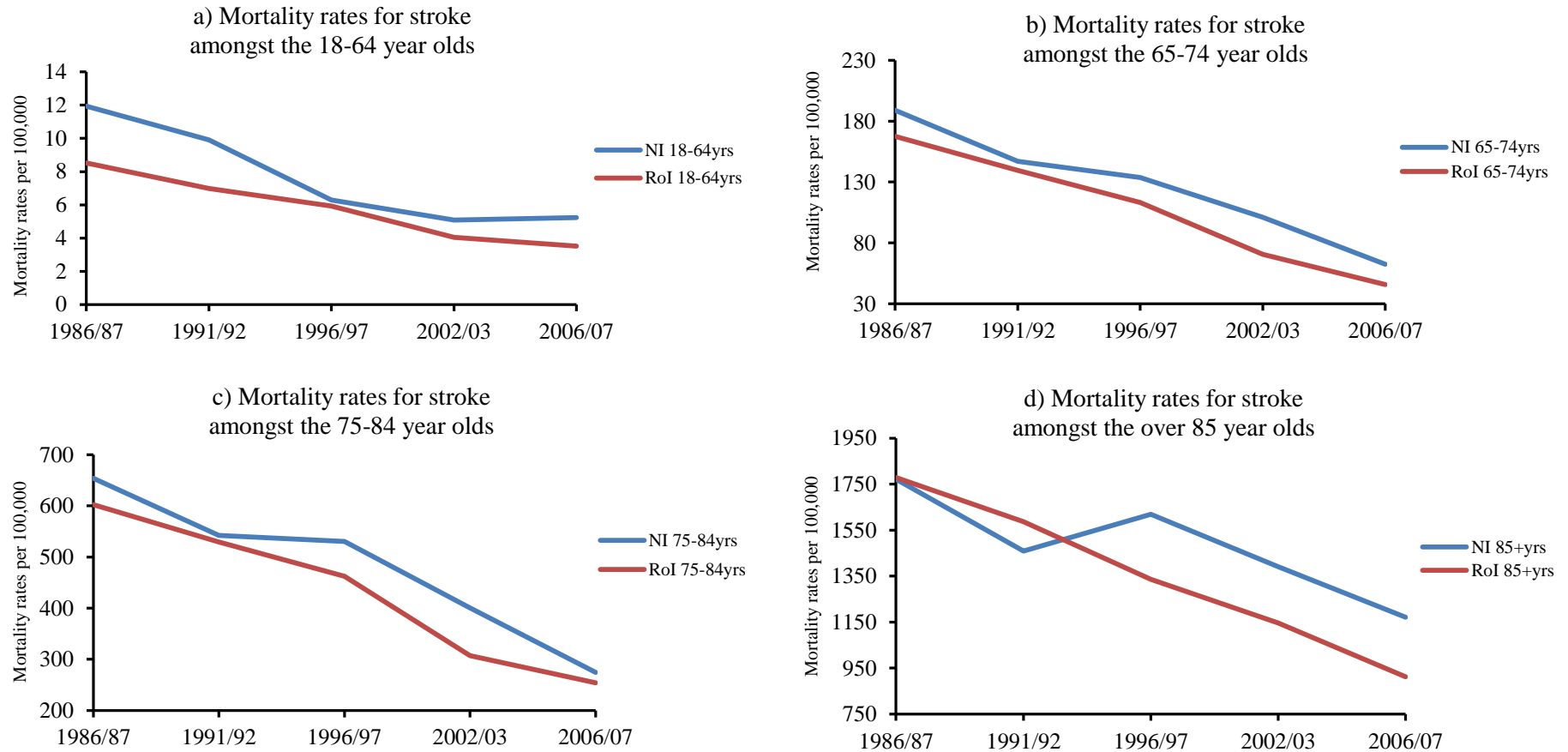


Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Zhou et al., 2014	China 2006-2010	Not specified	Poisson regression	0-27days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease Stroke	Day of week Seasonality Secular trends	Long lag structure Very short study period Subtropical climate Medium sample size
Atsumi et al, 2013	Japan 1993-2008	40+years	Case-crossover	0-10days	Maximum temperature	Cardiovascular disease Cardiac disease Stroke	Relative humidity Air pollution Long term trend Seasonality Day of week	Short-medium lag structure Medium study period Small sample size
Guo et al, 2013a	China 2004-2008	Not specified	Poisson regression	0-20days	Mean temperature	Ischaemic heart disease	Relative humidity Air pollution	Medium lag structure Short study period Small sample size
Guo et al, 2013b	Australia 2000-2004	Not specified	Poisson regression and case-crossover	0-10days	Maximum temperature	All-cause mortality	Relative humidity Air pollution	Short-medium lag structure Short study period Subtropical climate Sample size not specified
Wu et al., 2013	China 2006-2010	All ages	Poisson regression	0-27days	Mean temperature	All-cause mortality	Relative humidity Air pollution Long term trend Seasonality Day of week Public holidays	Long lag structure Short study period Sample size not specified
Barnett et al., 2012	United States 1987-2000	All ages	Poisson regression	0-21 days	Mean temperature	Cardiovascular disease Respiratory disease	Influenza Seasonality Day of week	Long lag structure Medium study period Temperate climate Sample size not specified

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Guo et al., 2012	Thailand 1999-2008	All ages	Poisson regression	0-21 days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease Cardiopulmonary	Relative humidity Air pollution Day of week Long term trend Seasonality	Long lag structure Short study period Subtropical climate Medium sample size
Klot et al., 2012	United States 1992-2000	65+ years	Poisson regression	0-25 days	Mean temperature	Cardiovascular disease	Relative humidity Long term trend Seasonality Day of week	Medium lag structure Short study period Sample size not specified
Miron et al., 2012	Spain 1975-2003	All ages	Arima models	0-15 days	Minimum temperature	All-cause mortality	Not adjusted for air pollution	Medium lag structure Long study period Temperate climate Sample size not specified
Tian et al., 2012	China 2000-2011	All ages	Poisson and case-crossover	0-15 days	Mean temperature	Cardiovascular disease	Relative humidity Long term trends Seasonality	Medium lag structure Short study period Small sample size
Wichmann et al., 2012	Denmark 1999-2006	19+ years	Case-crossover	0-5 days	Maximum temperature	Myocardial infarction	Air pollution Day of week Influenza Public holidays	Short lag structure Short study period Temperate climate Small sample size
Yang et al., 2012	China 2003-2007	All ages	Poisson regression	0-25 days	Mean temperature	All-cause mortality Cardiovascular disease Ischaemic heart disease Respiratory disease COPD, stroke	Air pollution	Long lag structure Short study period Medium sample size

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Goldberg et al., 2011	Canada 1984-2007	All ages	Poisson regression	0-30days	Maximum temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Seasonality Long term trends Day of week	Long lag structure Long study period Temperate climate Sample size not specified
Guo et al., 2011	China 2005-2007	All ages	Case-crossover combined with Poisson regression	0-27days	Maximum, Minimum and mean temperature	All-cause mortality Cardiovascular disease Respiratory disease Cardiopulmonary	Relative humidity Air pollution Seasonality Long term trends	Long lag structure Short study period Sample size not specified
Lin et al., 2011	Taiwan 1994-2007	65+years	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Relative humidity	Long lag structure Long study period Subtropical climate Sample size not specified
Liu et al., 2011	China 2003-2005	All ages	Poisson regression	0-29days	Mean temperature	Cardiovascular disease Ischaemic heart disease Respiratory disease Stroke	Relative humidity Air pollution Long term trends Seasonality Day of week Public holidays	Medium lag structure Short study period Small sample size
Rocklov et al., 2011	Sweden 1990-2002	All ages	Poisson regression	0-13days	Maximum, minimum apparent temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Influenza	Medium lag structure Medium study period Temperate climate Small sample size
Wichmann et al., 2011	Denmark 2002-2006	19+ years	Case-crossover	0-5days	Maximum apparent temperature	Cardiovascular disease Respiratory disease Stroke	Air pollution Public holidays Relative humidity Influenza	Short lag structure Short study period Temperate climate Small sample size

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Yu et al., 2011a	Australia 1996-2004	15+ years	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Relative humidity Air pollution Day of week Public holidays Influenza	Medium lag structure Short study period Subtropical climate Small sample size
Yu et al., 2011b	Australia 1996-2004	All ages	Poisson regression	0-20days	Maximum, minimum, mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Relative humidity Air pollution	Medium lag structure Short study period Subtropical climate Small sample size
Gomez-Acebo et al., 2010	Spain 2004-2005	All ages	Case-crossover	0-6days	Maximum, minimum temperature	Mortality not defined	Relative humidity Wind speed Day of week	Short lag structure Short study period Temperate climate Sample size not specified
Anderson and Bell, 2009	United States 1987-2000	All ages	Poisson regression	0-28days	Mean temperature	Cardiovascular disease Respiratory disease	Air pollution	Long lag structure Long study period Large sample size
Hashizume et al., 2009	Bangladesh 1994-2002	All ages	Poisson regression	0-13days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Long term trends Seasonality Day of week	Medium lag structure Short study period Subtropical climate Small sample size
Kysely et al., 2009	Czech Republic 1986-2006	25+ years	Poisson regression	0-20days	Maximum temperature	Cardiovascular disease	Excluded influenza and acute respiratory infections	Medium lag structure Medium study period Temperate climate Sample size not specified
Analitis et al., 2008	Europe 1990-2000	All ages	Poisson regression	0-30days	Minimum temperature	All-cause mortality Cardiovascular disease Respiratory disease Stroke	Air pollution Air pressure Long term trends Day of week Calendar month Influenza	Long lag structure Medium study period Temperate climate Large sample size

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Carder et al., 2008	Scotland 1981-2001	Not specified	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Seasonality Day of week	Longer lag structure Long study period Temperate climate Sample size not specified
McMichael et al., 2008	Multi country Period unknown	All ages	Poisson regression	0-13days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease Cardiorespiratory Non-cardiorespiratory	Air pollution Relative humidity Seasonality Day of week	Medium lag structure Study period unknown Temperate, subtropical and tropical climate Sample size not specified
Revich and Shaposhnikov, 2008	Russia 2000-2006	All ages	Poisson regression	0-28days	Mean temperature	All-cause mortality Ischaemic heart disease Stroke Chronic lower respiratory disease	None	Long lag structure Short study period Temperate climate Sample size not specified
Hajat et al., 2007	England, Wales, 1993-2003	All ages	Poisson regression	0-13days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Long term trends Seasonality	Medium lag structure Long study period Temperate climate Sample size not specified
Medina-Ramón & Schwartz, 2007	United States 1989-2000	Not specified	Case-crossover	0-1days	Maximum temperature	All-cause mortality Myocardial infarction Cardiac arrest	Air pollution	Short lag structure Medium study period Very large sample size

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Medina-Ramón et al., 2006	United States 1989-2000	All ages	Case-only	0-2days	Maximum temperature	All-cause mortality Cardiovascular disease Ischaemic heart disease Myocardial infarction COPD, pneumonia Stroke	Air pollution Relative humidity	Short lag structure Medium study period Very large sample size
Barnett et al., 2005	21 countries 1980-1995	35-64 years	Poisson regression	1-14days	Mean temperature	Cardiovascular disease Myocardial infarction	Long term trends Seasonality Day of week	Medium lag structure Medium study period Subtropical and temperate climate Small sample size
Carder et al., 2005	Scotland 1981-2001	All ages	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Long term trends Seasonality Day of week	Longer lag structure Long study period Temperate climate Sample size not specified
Diaz et al., 2005	Spain 1986-1997	65+ years	Poisson regression and Arima models	1-14days	Maximum temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Influenza Seasonality	Medium lag structure Medium study period Temperate climate Medium sample size
Goodman et al., 2004	Republic of Ireland, 1980-1996	All ages	Poisson regression	1-41 days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Relative humidity Long term trends Seasonality Day of week Influenza	Longer lag structure Medium study period Temperate climate Small sample size
Hong et al., 2003	Korea 1998-2008	All ages	Case-crossover	0-4days	Mean temperature	Stroke	Air pollution Relative humidity Air pressure Day of week	Short lag structure Short study period Subtropical climate Very small sample size

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
O'Neil et al., 2003	United States 1986-1993	All ages	Poisson regression	0-3days	Mean apparent temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Air pressure Long term trends Seasonality Day of week	Short lag structure Short study period Large sample size
Braga et al., 2002	United States 1986-1993	All ages	Poisson regression	0-20days	Mean temperature	Cardiovascular disease Myocardial infarction Respiratory mortality COPD, pneumonia	Air pressure Long term trends Seasonality Day of week	Medium lag structure Short study period Sample size not specified
Hajat & Haines, 2002	England 1992-1995	65+ years	Poisson regression	0-24days	Mean temperature	Cardiovascular disease Respiratory disease	Air pollution Long term trends Seasonality Day of week Public holidays	Long lag structure Short study period Temperate climate Small sample size
Laschewski & Jendritzsky, 2002	Germany 1968-1997	All ages	Poisson regression	1-14days	Mean perceived temperature	All-cause mortality	Seasonality Influenza	Medium lag structure Long study period Temperate location Very large sample size
Braga et al., 2001	United States 1986-1993	All ages	Poisson regression	0-21days	Mean temperature	All-cause mortality	Relative humidity Air pressure Seasonality Day of week	Long lag structure Short study period Sample size not specified
Huynen et al., 2001	The Netherlands 1979-1997	All ages	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Long term trends Seasonality	Longer lag structure Long study period Temperate climate Sample size not specified

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
Keatinge & Donaldson, 2001	England 1976-1995	50+ years	Poisson regression	0-24days	Mean temperature	All-cause mortality	Air pollution Long term trends Seasonality Influenza	Long lag structure Long study period Temperate climate Sample size not specified
Rossum et al., 2001	1967-1970 plus 25 year follow up	40+ years	Poisson regression	No lags	Not defined	All-cause mortality Cardiovascular disease Ischaemic heart disease Respiratory disease Stroke	Seasonality	No lag structure Long study period Temperate climate Small sample size
Gemmell et al., 2000	Scotland 1981-1993	All ages	Poisson regression	0-35days	Mean temperature	Cardiovascular disease Ischaemic heart disease Respiratory disease	Influenza	Longer lag structure Medium study period Temperate climate Sample size not specified
Sheth et al., 1999	Canada 1980-1982 1990-1992	All ages	Linear regression	No lags	Not defined	Myocardial infarction Stroke	None	No lag structure Short study period Temperate climate Medium sample size
Ballester et al., 1997	Spain 1991-1993	70+years	Poisson regression	0-14days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory Disease	Air pollution Relative humidity Seasonality Day of week Influenza	Medium lag structure Short study period Temperate climate Sample size not specified
Donaldson & Keatinge, 1997	England 1976-1992	50+ years	Poisson regression	0-40days	Mean temperature	All-cause mortality Ischaemic heart disease Respiratory disease Stroke	None	Longer lag structure Medium study period Temperate climate Sample size not specified

Table 1. A critical appraisal of epidemiological studies of the cold weather-mortality relationship (continued)

Authors, year	Study location Study period	Study population	Study Design	Lag structure	Temperature Metrics	Mortality parameters	Potential confounders	Comments
The Eurowinter Group, 1997	Europe 1988-1992	50+years	Poisson regression	0-12days	Mean temperature	All-cause mortality Cardiovascular disease Ischaemic heart disease Respiratory disease	Influenza	Medium lag structure Short study period Temperate climate Medium sample size
Kunst et al., 1993	The Netherlands 1979-1987	Not specified	Poisson regression	0-30days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Long term trends Seasonality Influenza	Long lag structure Short study period Sample size not specified Population not specified
Mackenbach et al., 1993	The Netherlands 1979-1987	Not specified	Poisson regression	0-20days	Mean temperature	All-cause mortality Cardiovascular disease Respiratory disease	Air pollution Relative humidity Secular trends Seasonality Day of week Influenza	Long lag structure Short study period Temperate climate Sample size not specified Population not specified The difference between daily maximum and minimum temperatures was included as a potential confounder

Table 2. Estimated mortality percentage change per 1°C decrease in minimum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.2 (1.0, 1.3)	0.8 (0.6, 1.0)	0.8 (0.6, 1.0)	0.6 (0.4, 0.8))	0.3 (0.1, 0.5)	3.7 (2.8, 4.6)§
CVD	1.4 (1.0, 1.7)	0.8 (0.5, 1.2)	0.7 (0.02, 1.1)	0.6 (0.3, 0.9)	0.3 (-0.1, 0.6)	3.5 (2.3, 4.8)∂
IHD	1.5 (1.1, 1.8)	0.5 (0.1, 0.9)	0.8 (0.4, 1.2)	0.5 (0.1, 0.9)	0.3 (-0.1, 0.7)	3.2 (1.8, 4.7)∂
MI	1.4 (1.0, 2.0)	0.6 (0.1, 1.0)	0.7 (0.3, 1.2)	0.5 (0.1, 0.9)	0.3 (-0.1, 0.8)	3.2 (1.5, 5.0)∂
Respiratory Disease	1.6 (1.1, 2.0)	2.1 (1.6, 2.5)	1.7 (1.3, 2.2)	1.7 (1.2, 2.1)	0.9 (0.5, 1.4)	8.0 (5.7, 10.3)§
COPD	1.3 (0.5, 2.0)	2.2 (1.5, 3.0)	1.7 (0.9, 2.4)	1.8 (1.0, 2.5)	0.9 (0.2, 1.7)	7.9 (4.2, 11.5) §
Pneumonia	1.9 (1.2, 2.6)	1.8 (1.2, 2.5)	1.9 (1.2, 2.6)	1.5 (0.8, 2.1)	0.8 (0.1, 1.5)	7.9 (4.5, 11.3) §
Stroke	1.4 (0.8, 2.0)	0.3 (-0.3, 0.9)	0.8 (0.2, 0.9)	0.3 (-0.2, 0.9)	0.02 (-0.6, 0.6)	2.5 (0.7, 4.3)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold Season = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1-3.

Table 3. Estimated mortality percentage change per 1°C decrease in minimum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.1 (0.8, 1.4)	0.9 (0.7, 1.2)	0.8 (0.5, 1.1)	0.1 (-0.1, 0.4)	2.8 (2.0, 3.6) †
CVD	1.0 (0.5, 1.5)	0.7 (0.3, 1.2)	0.5 (0.0, 1.0)	0.0 (-0.5, 0.5)	2.3 (0.8, 3.7) †
IHD	0.9 (0.3, 1.5)	0.7 (0.1, 1.2)	0.6 (0.0, 1.1)	0.3 (-0.3, 0.9)	2.1 (0.5, 3.8) †
MI	1.0 (0.4, 1.6)	0.6 (0.0, 1.2)	0.6 (0.0, 1.2)	0.4 (-0.2, 1.0)	2.2 (0.4, 4.0) †
Respiratory Disease	1.9 (1.2, 2.5)	2.3 (1.7, 2.9)	2.0 (1.4, 2.6)	0.5 (-0.1, 1.2)	6.2 (4.3, 8.1) †
COPD	2.3 (1.0, 3.6)	2.2 (0.9, 3.5)	1.1 (-0.2, 2.4)	0.3 (-1.0, 1.7)	4.6 (2.0, 7.2) ∂
Pneumonia	1.5 (0.7, 2.3)	2.4 (1.7, 3.2)	2.1 (1.3, 2.9)	0.5 (-0.3, 1.3)	6.0 (3.6, 8.4) †
Stroke	1.0 (0.2, 1.8)	0.7 (-0.1, 1.5)	1.3 (0.5, 2.1)	0.6 (-0.2, 1.4)	3.0 (0.6, 5.4) †

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold Season = October to March. †Cumulative change calculated for lag of week 1 to 3. ∂Cumulative change calculated for lag of week 1 to 2.

Table 4. Estimated mortality percentage change per 1°C decrease in mean temperature in the Republic of Ireland during the cold season‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.3 (1.1, 1.5)	0.8 (0.6, 1.0)	0.9 (0.7, 1.1)	0.6 (0.4, 0.8)	0.3 (0.1, 0.5)	4.0 (2.9, 5.0)§
CVD	1.5 (1.2, 1.9)	0.9 (0.5, 1.3)	0.8 (0.02, 1.1)	0.7 (0.3, 1.0)	0.1 (-0.2, 0.5)	3.9 (2.4, 5.4)∂
IHD	1.7 (1.2, 2.1)	0.5 (0.1, 0.9)	0.9 (0.5, 1.3)	0.5 (0.1, 0.9)	0.2 (-0.2, 0.6)	3.6 (1.9, 5.2)∂
MI	1.4 (1.0, 1.9)	0.6 (0.1, 1.0)	0.7 (0.3, 1.2)	0.5 (0.1, 0.9)	0.3 (-0.1, 0.8)	3.7 (1.6, 5.7)∂
Respiratory Disease	1.7 (1.1, 2.2)	2.2 (1.7, 2.7)	1.8 (1.3, 2.3)	1.8 (1.3, 2.3)	0.8 (0.3, 1.4)	8.3 (5.7, 10.9)§
COPD	1.5 (0.6, 2.3)	2.3 (1.5, 3.1)	1.7 (0.9, 2.5)	2.0 (1.2, 2.8)	0.7 (-0.1, 1.5)	7.5 (4.1, 10.8)∂
Pneumonia	2.0 (1.3, 2.8)	2.0 (1.3, 2.8)	2.1 (1.3, 2.8)	1.5 (0.8, 2.3)	0.8 (0.0, 1.6)	8.5 (4.6, 12.3)§
Stroke	1.8 (1.1, 2.5)	0.3 (-0.4, 1.0)	1.0 (0.3, 1.7)	0.3 (-0.4, 1.0)	0.1 (-0.5, 0.8)	3.1 (1.0, 5.3)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold Season = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

Table 5. Estimated mortality percentage change per 1°C decrease in mean temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.3 (1.0, 1.6)	0.9 (0.6, 1.2)	0.9 (0.5, 1.2)	0.1 (-0.2, 0.4)	3.2 (1.9, 4.4) †
CVD	1.1 (0.5, 1.6)	0.7 (0.1, 1.2)	0.6 (0.0, 1.2)	0.1 (-0.5, 0.6)	2.3 (0.1, 4.5) †
IHD	1.1 (0.5, 1.8)	0.5 (-0.1, 1.2)	0.8 (0.1, 1.4)	0.4 (-0.2, 1.1)	2.0 (-0.6, 4.5) †
MI	1.2 (0.5, 1.9)	0.3 (-0.3, 1.0)	0.8 (0.2, 1.5)	0.5 (-0.2, 1.2)	1.9 (-0.9, 4.7) †
Respiratory Disease	2.3 (1.6, 3.1)	2.3 (1.6, 3.0)	2.4 (1.7, 3.1)	0.5 (-0.2, 1.2)	7.5 (4.6, 10.5) †
COPD	3.1 (1.6, 4.7)	2.2 (0.7, 3.6)	1.3 (-0.2, 2.8)	0.3 (-1.2, 1.8)	5.3 (2.3, 8.3) †
Pneumonia	1.7 (0.7, 2.7)	2.4 (1.5, 3.4)	2.5 (1.6, 3.5)	0.6 (-0.3, 1.5)	7.3 (3.6, 11.0) †
Stroke	1.2 (0.3, 2.1)	0.7 (-0.2, 1.6)	1.4 (0.5, 2.3)	0.8 (-0.1, 1.7)	4.1 (0.4, 7.7) †

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold Season = October to March. βCumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3. ‡Cumulative change calculated for lag of week 1 to 2.

Table 6. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-2007 with DIFFT1 as an independent variable.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.3 (1.1, 1.5)	0.8 (0.5, 1.0)	0.9 (0.6, 1.1)	0.5 (0.3, 0.8)	0.2 (0.0, 0.5)	3.7 (2.6, 4.8)§
CVD	1.5 (1.1, 1.9))	0.9 (0.4, 1.5)	0.7 (0.3, 1.1)	0.6 (0.2, 1.0)	0.02 (-0.4, 0.4)	3.7 (2.2, 5.3)∂
IHD	1.6 (1.2, 2.1)	0.4 (0.0, 0.9)	0.8 (0.4, 1.3)	0.5 (0.1, 0.9)	0.1 (-0.3, 0.6)	3.4 (1.6, 5.2)∂
MI	1.6 (1.0, 2.1)	0.6 (0.1, 1.1))	0.8 (0.3, 1.4)	0.6 (0.03, 1.1))	0.2 (-0.3, 0.8)	3.6 (4.8, 10.2)∂
Respiratory Disease	1.5 (1.0, 2.1)	2.0 (1.4, 2.5)	1.7 (1.1, 2.2)	1.7 (1.1, 2.2))	0.7 (0.1, 1.2)	7.5 (4.8, 10.2)§
COPD	1.5 (0.6, 2.4)	1.9 (1.1, 2.8)	1.7 (0.8, 2.5)	2.0 (1.2, 2.9)	0.4 (-0.5, 1.2)	7.1 (3.7, 10.5)∂
Pneumonia	1.8 (1.0, 2.6)	2.0 (1.2, 2.8)	2.0 (1.2, 2.8)	1.3 (0.5, 2.1)	0.7 (-0.2, 1.7)	7.2 (4.0, 10.4)∂
Stroke	1.9 (1.1, 2.6)	0.2 (-0.5, 0.9)	1.0 (0.3, 1.7)	0.1 (-0.6, 0.8)	0.3 (-0.4, 1.0)	3.1 (1.0, 5.2)†

Abbreviations: DIFFT1 = Maximum temperature – minimum temperature (independent variable).

CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold period = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

Table 7. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-2007 with DIFFT2 as an independent variable.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.3 (1.1, 1.5)	0.8 (0.5, 1.0)	0.9 (0.6, 1.1)	0.5 (0.3, 0.8)	0.2 (0.0, 0.5)	3.7 (2.6, 4.8)§
CVD	1.5 (1.1, 1.9))	0.9 (0.5, 1.5)	0.7 (0.3, 1.1)	0.6 (0.2, 1.0)	0.02 (-0.4, 0.4)	3.7 (2.2, 5.3)∂
IHD	1.6 (1.2, 2.1)	0.4 (0.0, 0.9)	0.8 (0.4, 1.3)	0.5 (0.1, 0.9)	0.1 (-0.3, 0.6)	3.4 (1.6, 5.2)∂
MI	1.6 (1.0, 2.1)	0.6 (0.1, 1.1))	0.8 (0.3, 1.4)	0.6 (0.03, 1.1))	0.2 (-0.3, 0.8)	3.6 (4.8, 10.2)∂
Respiratory Disease	1.5 (1.0, 2.1)	2.0 (1.4, 2.5)	1.7 (1.1, 2.2)	1.7 (1.1, 2.2))	0.7 (0.1, 1.2)	7.5 (4.8, 10.2)§
COPD	1.5 (0.6, 2.4)	1.9 (1.1, 2.8)	1.7 (0.8, 2.5)	2.0 (1.2, 2.9)	0.4 (-0.5, 1.2)	7.1 (3.6, 10.5)∂
Pneumonia	1.8 (1.0, 2.6)	2.0 (1.2, 2.8)	2.0 (1.2, 2.8)	1.3 (0.5, 2.1)	0.7 (-0.2, 1.7)	7.2 (4.0, 10.4)∂
Stroke	1.9 (1.1, 2.6)	0.2 (-0.5, 0.9)	1.0 (0.3, 1.7)	0.1 (-0.6, 0.8)	0.3 (-0.4, 1.0)	3.1 (1.0, 5.2)†

Abbreviations: DIFFT2 = Maximum temperature – mean temperature (independent variable).

CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold season = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

Table 8. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007 with DIFFT1 as an independent variable.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.4 (1.0, 1.7)	0.8 (0.5, 1.1)	0.8 (0.5, 1.2)	0.1 (-0.3, 0.4)	3.0 (2.0, 4.0)†
CVD	1.1 (0.5, 1.7)	0.5 (-0.02, 1.1)	0.7 (0.02, 1.3)	0.1 (-0.5, 0.7)	2.4 (0.6, 4.1)†
IHD	1.3 (0.6, 2.0)	0.3 (-0.4, 0.9)	0.9 (0.2, 1.6)	0.5 (-0.2, 1.1)	2.5 (0.5, 4.5)†
MI	1.4 (0.6, 2.2)	0.1 (-0.6, 0.8)	1.0 (0.2, 1.7)	0.4 (-0.3, 1.2)	2.4 (0.2, 4.6)†
Respiratory Disease	2.6 (1.8, 3.4)	2.0 (1.2, 2.7)	2.5 (1.8, 3.3)	0.5 (-0.2, 1.3)	7.6 (4.6, 10.7)†
COPD	3.4 (1.8, 5.1)	1.9 (0.3, 3.4)	1.4 (-0.1, 3.0)	0.4 (-1.2, 2.0)	5.3 (2.1, 8.5)†
Pneumonia	1.8 (0.7, 2.8)	2.1 (1.1, 3.0)	2.8 (1.8, 3.7)	0.7 (-0.2, 1.7)	7.3 (3.4, 11.2)†
Stroke	1.2 (0.2, 2.2)	0.7 (-0.2, 1.6)	1.2 (0.3, 2.2)	1.0 (0.0, 1.9)	4.1 (0.3, 7.9)∂

Abbreviations: DIFFT1 = Maximum temperature – minimum temperature (independent variable).

CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold season = October to March. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

Table 9. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007 with DIFFT2 as an independent variable.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.4 (1.0, 1.7)	0.8 (0.5, 1.1)	0.8 (0.5, 1.2)	0.1 (-0.3, 0.4)	3.0 (2.0, 4.0)†
CVD	1.1 (0.5, 1.7)	0.5 (-0.02, 1.1)	0.7 (0.02, 1.3)	0.1 (-0.5, 0.7)	2.4 (0.6, 4.1)†
IHD	1.3 (0.6, 2.0)	0.3 (-0.4, 0.9)	0.9 (0.2, 1.6)	0.5 (-0.2, 1.1)	2.5 (0.5, 4.5)†
MI	1.4 (0.6, 2.2)	0.1 (-0.6, 0.8)	1.0 (0.2, 1.7)	0.4 (-0.3, 1.2)	2.4 (0.2, 4.6)†
Respiratory Disease	2.6 (1.8, 3.4)	2.0 (1.2, 2.7)	2.5 (1.8, 3.3)	0.5 (-0.2, 1.3)	7.1 (4.8, 9.4)†
COPD	3.4 (1.8, 5.1)	1.1 (0.3, 3.4)	1.4 (-0.1, 3.0)	0.4 (-1.2, 2.0)	5.3 (2.1, 8.5)β
Pneumonia	1.8 (0.8, 2.8)	2.1 (1.1, 3.0)	2.8 (1.8, 3.7)	0.7 (-0.2, 1.7)	6.6 (3.7, 9.5)δ
Stroke	1.2 (0.2, 2.2)	0.7 (-0.2, 1.6)	1.2 (0.3, 2.2)	1.0 (0.01, 1.9)	4.1 (0.3, 7.9)†

Abbreviations: DIFFT2 = Maximum temperature – mean temperature (independent variable).

CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold season = October to March. δCumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3. βCumulative change calculated for lag of week 1 to 2.

Table 10. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-1991.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.1 (0.7, 1.5)	0.9 (0.5, 1.3)	0.8 (0.5, 1.1)	1.1 (0.8, 1.4)	0.8 (0.5, 1.2)	4.7 (3.0, 6.5)§
CVD	1.2 (0.6, 1.8)	1.1 (0.5, 1.7)	0.7 (0.02, 1.3)	1.1 (0.5, 1.6)	0.4 (-0.1, 1.0)	4.1 (1.8, 6.4)∂
IHD	1.4 (0.7, 2.1)	0.3 (-0.4, 1.0)	0.8 (0.2, 1.5)	0.9 (0.3, 1.5)	0.6 (-0.03, 1.3)	3.5 (0.8, 6.1)∂
MI	1.4 (0.6, 2.2)	0.4 (-0.3, 1.2)	1.0 (0.3, 1.7)	0.8 (0.04, 1.5)	0.6 (-0.1, 1.3)	3.6 (0.6, 6.6)∂
Respiratory Disease	1.4 (0.4, 2.3)	1.8 (0.9, 2.7)	1.6 (0.8, 2.5)	1.6 (0.8, 2.5)	2.5 (1.6, 3.3)	8.9 (4.5, 13.3)§
COPD	2.0 (0.6, 3.4)	1.2 (-0.2, 2.5)	1.5 (0.2, 2.8)	1.6 (0.4, 2.9)	1.6 (0.3, 2.9)	7.9 (1.3, 15.7)§
Pneumonia	1.1 (0.3, 2.5)	1.7 (0.4, 3.1)	2.3 (1.0, 3.6)	1.4 (0.1, 2.7)	2.6 (1.3, 3.9)	9.12.4, 15.7)§
Stroke	1.3 (0.2, 2.4)	1.2 (0.1, 2.2)	0.6 (-0.4, 1.6)	1.6 (0.6, 2.6)	0.1 (-1.0, 1.1)	4.6 (0.4, 8.9)∂

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold season = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4.

Table 11. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1992-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.4 (1.1, 1.7)	0.6 (0.3, 0.9)	0.8 (0.5, 1.1)	0.1 (-0.2, 0.4)	0.2 (-0.1, 0.5)	2.8 (1.4, 4.2)†
CVD	1.7 (1.2, 2.3)	0.7 (0.2, 1.2)	0.6 (0.02, 1.1)	0.2 (-0.3, 0.7)	0.3 (-0.2, 0.8)	3.0 (1.8, 4.1)†
IHD	1.8 (1.2, 2.4)	0.5 (-0.1, 1.0)	0.7 (0.1, 1.3)	0.1 (-0.5, 0.7)	0.3 (-0.3, 0.9)	3.0 (1.2, 4.8)†
MI	1.8 (1.1, 2.5)	0.7 (0.0, 1.4)	0.6 (-0.2, 1.3)	0.3 (-0.5, 1.0)	0.1 (-0.6, 0.8)	2.5 (1.0, 3.9)∂
Respiratory Disease	1.7 (1.0, 2.4)	2.0 (1.3, 2.6)	1.7 (1.0, 2.4)	1.7 (1.0, 2.4)	0.4 (-0.2, 1.1)	6.6 (3.2, 10.1)§
COPD	1.2 (0.1, 2.3)	2.4 (1.3, 3.5)	1.9 (0.7, 3.0)	2.4 (1.2, 3.5)	0.5 (-0.6, 1.6)	7.8 (3.3, 12.4)§
Pneumonia	2.3 (1.3, 3.3)	2.1 (1.1, 3.1)	1.8 (0.7, 2.8)	1.2 (0.2, 2.2)	0.3 (-0.7, 1.3)	7.3 (3.3, 11.4)§
Stroke	2.2 (1.3, 3.2)	0.4 (-0.5, 1.4)	1.2 (0.2, 2.1)	-1.2 (0.3, 2.2)	0.5 (-0.4, 1.5)	2.9 (0.1, 5.8)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold season = October to March. §Cumulative change for lag of week 1 to 4.†Cumulative change calculated for lag of week 1 to 3. ∂Cumulative change calculated for lag of week 1 to 2

Table 12. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-1991.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.4 (0.8, 1.9)	1.2 (0.7, 1.8)	1.2 (0.7, 1.8)	0.4 (-0.1, 0.9)	3.9 (2.2, 5.5)†
CVD	1.0 (0.1, 2.0)	0.5 (-0.3, 1.4)	0.8 (0.02, 1.7)	0.6 (-0.2, 1.5)	2.4 (-0.2, 5.1)†
IHD	1.6 (0.6, 2.7)	0.2 (-0.8, 1.3)	1.1 (0.2, 2.1)	1.0 (0.0, 2.0)	2.5 (-0.5, 5.6)§
MI	1.8 (0.7, 3.0)	0.6 (-0.5, 1.7)	1.3 (0.3, 2.3)	0.8 (-0.2, 1.9)	2.6 (-0.7, 5.8)†
Respiratory Disease	2.7 (1.4, 4.1)	2.4 (1.1, 3.6)	2.6 (1.4, 3.8)	0.8 (-0.4, 2.0)	7.7 (3.9, 18.3)†
COPD	5.4 (2.4, 8.4)	3.2 (0.3, 6.2)	1.0 (-1.7, 3.7)	1.3 (-1.4, 4.0)	8.6 (2.7, 14.5)∂
Pneumonia	1.5 (-0.1, 3.2)	2.2 (0.6, 3.8)	2.8 (1.3, 4.2)	1.0 (-0.5, 2.5)	6.5 (1.8, 11.2)†
Stroke	1.2 (-0.3, 2.8)	1.5 (0.04, 3.0)	2.2 (0.8, 3.6)	0.8 (-0.6, 2.3)	5.0 (0.4, 9.5)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold season = October to March. §Cumulative change for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3. ∂Cumulative change calculated for lag of week 1 to 2.

Table 13. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1992-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.5 (1.1, 1.9)	0.5 (0.1, 0.9)	0.6 (0.1, 0.9)	0.3 (-0.1, 0.7)	2.6 (1.3, 3.8)†
CVD	1.3 (0.5, 2.0)	0.4 (-0.3, 1.2)	0.7 (0.02, 1.5)	0.4 (-0.4, 1.2)	2.4 (0.1, 4.6)†
IHD	1.3 (0.4, 2.1)	0.6 (-0.3, 1.4)	0.8 (-0.1, 1.7)	0.1 (-0.8, 1.0)	1.3 (0.4, 2.1)∂
MI	1.3 (0.3, 2.2)	0.4 (-0.5, 1.4)	0.7 (-0.3, 1.7)	0.1 (-0.9, 1.2)	1.3 (0.3, 2.2)∂
Respiratory Disease	2.6 (1.6, 3.5)	1.7 (0.8, 2.6)	2.5 (1.5, 3.5)	0.3 (-0.7, 1.3)	6.8 (3.9, 9.7)†
COPD	3.1 (1.3, 5.0)	1.1 (-0.7, 2.9)	1.6 (-0.4, 3.5)	0.1 (-1.8, 2.0)	3.1 (1.3, 5.0)∂
Pneumonia	2.0 (0.7, 3.2)	2.0 (0.8, 3.2)	2.8 (1.5, 4.0)	0.5 (-0.8, 1.8)	6.7 (3.0, 10.4)†
Stroke	1.6 (0.4, 2.9)	0.05 (-1.1, 1.2)	0.3 (-1.0, 1.6)	0.9 (-0.3, 2.2)	1.6 (0.4, 2.9)∂

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold season = October to March. †Cumulative change calculated for lag of week 1 to 3. ∂Cumulative change calculated for lag of week 1.

Table 14. Total number of deaths stratified by age and gender in the Republic of Ireland and Northern Ireland between 1984 and 2007.

Cause of Death	Gender	Republic of Ireland								Northern Ireland							
		All Year				Cold Period				All Year				Cold Period			
		All ages	18-64 yr.	65-74 yr.	75+ yr.	All ages	18-64 yr.	65-74 yr.	75+ yr.	All ages	18-64 yr.	65-74 yr.	75+ yr.	All ages	18-64 yr.	65-74yr.	75+ yr.
All-cause Mortality	Male	367548	82345	100866	184337	196918	39411	53776	93136	168304	40129	46253	81922	89471	19248	24425	40922
	Female	341562	52572	65219	223771	184181	24471	34704	116771	179632	26934	33587	11911	96612	12723	17801	62179
CVD	Male	127771	28183	37217	62371	68745	14677	20026	31487	57434	13868	17520	26046	30595	7168	9328	12939
	Female	103469	8220	18991	76258	56196	4312	10210	39949	51892	4897	10566	36429	28140	2684	5738	18798
IHD	Male	101936	23909	31549	46472	54697	12450	16910	23309	44975	11844	14243	18888	23990	6144	7608	9328
	Female	72103	5997	14898	51206	39066	3167	7989	26636	34911	3581	7889	23441	18932	1980	4243	12061
MI	Male	71695	16429	23351	31912	38526	8551	12516	16001	37543	9046	12208	16289	20063	4693	6515	8058
	Female	49351	4235	11189	33925	26868	2246	6058	17638	30452	2963	7129	20360	16602	1641	3853	10533
Respiratory Disease	Male	54019	5348	12151	36520	31263	2858	7169	19948	26398	3058	5634	17706	15217	1550	3264	9635
	Female	52180	3601	7966	40613	30680	2024	4736	22933	31651	2357	4123	25171	18605	1193	2418	14405
COPD	Male	24523	2228	6913	15371	14435	1343	4144	8360	7765	920	2357	4488	4465	568	1358	2344
	Female	16115	1422	4140	10546	9729	889	2570	5892	5627	736	1628	3263	3379	458	996	1794
Pneumonia	Male	21613	1556	3443	16470	12405	868	2018	9042	14113	1081	2193	10839	8163	564	1286	6010
	Female	27636	1029	2559	23933	16051	614	1458	13580	21843	819	1758	19266	12818	416	1015	11115
Stroke	Male	28235	3637	6932	17666	15273	1915	3719	9033	14781	1951	3552	9278	7865	1005	1866	4662
	Female	38902	2978	5834	30090	21183	1520	3139	15877	24760	1696	3468	19596	13332	866	1838	10278

Abbreviations: COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction, total = male and female, and yr. = years.
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Table 15. Weather descriptive for the Republic of Ireland and Northern Ireland between 1984 and 2007.

Season	Temperature*	Republic of Ireland					Northern Ireland				
		Mean ± SD	99th	Percentiles		1 st	Mean ± SD	99th	Percentiles		1 st
				90 th	10 th				90 th	10 th	
All year	Mean	9.7 ± 4.4	19.0	15.4	4.1	0.4	9.1 ± 4.4	18.6	15.2	3.4	0.0
	Minimum	6.3 ± 4.4	15.2	12.1	0.6	-3.5	5.9 ± 4.5	15.0	11.9	0.0	-3.9
	Maximum	13.0 ± 4.8	24.1	19.4	7.0	3.1	12.4 ± 4.9	23.5	18.9	6.1	2.5
Summer ¹	Mean	14.7 ± 2.3	20.5	17.8	11.9	9.4	14.4 ± 2.4	20.1	17.5	11.4	8.9
	Minimum	10.9 ± 2.6	16.5	14.0	7.6	4.3	10.6 ± 2.7	16.2	13.9	7.1	3.6
	Maximum	18.6 ± 2.8	26.4	22.3	15.2	12.6	18.1 ± 2.8	25.7	21.9	14.7	12.0
Winter Months ²	Mean	5.8 ± 2.9	11.8	9.5	2.0	-1.1	4.9 ± 2.7	10.7	8.3	1.5	-1.4
	Minimum	3.1 ± 3.3	10.3	7.4	-1.2	-4.9	2.2 ± 3.2	9.5	6.4	-1.8	-5.6
	Maximum	8.6 ± 2.8	13.9	12.0	4.8	1.5	7.6 ± 2.7	13.2	11.1	4.0	1.0
Cold Period ³	Mean	7.0 ± 3.2	14.4	11.1	2.9	-0.4	6.3 ± 3.2	14.0	10.5	2.3	-0.8
	Minimum	4.1 ± 3.7	16.0	8.8	-0.5	-4.4	3.4 ± 3.6	12.0	8.3	-1.0	-4.9
	Maximum	10.0 ± 3.2	17.4	14.0	5.7	2.2	9.1 ± 3.3	16.7	13.2	4.9	1.7

Abbreviations: SD = standard deviation, * in degrees Celsius (°C), ¹ Summer = June to August, ² Winter Months = December to February, and ³ Cold Period = October to March.
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Table 16. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.3 (1.1, 1.5)	0.8 (0.5, 1.0)	0.9 (0.6, 1.1)	0.5 (0.3, 0.8)	0.2 (0.02, 0.5)	3.7 (2.6, 4.8)§
CVD	1.5 (1.1, 1.9)	0.9 (0.5, 1.3)	0.7 (0.3, 1.1)	0.6 (0.2, 1.0)	0.02 (-0.4, 0.4)	3.7 (2.2, 5.3)∂
IHD	1.6 (1.2, 2.1)	0.4 (0.0, 0.9)	0.8 (0.4, 1.3)	0.5 (0.1, 0.9)	0.1 (-0.3, 0.6)	3.4 (1.6, 5.2)∂
MI	1.6 (1.0, 2.1)	0.6 (0.1, 1.1)	0.8 (0.3, 1.4)	0.6 (0.03, 1.1)	0.2 (-0.3, 0.8)	3.6 (1.5, 5.7)∂
Respiratory Disease	1.5 (1.0, 2.1)	2.0 (1.5, 2.5)	1.7 (1.2, 2.2)	1.7 (1.1, 2.2)	0.7 (0.1, 1.2)	7.5 (4.8, 10.2)§
COPD	1.5 (0.6, 2.4)	1.9 (1.1, 2.8)	1.6 (0.8, 2.5)	2.0 (1.2, 2.9)	0.4 (-0.5, 1.2)	7.1 (3.6, 10.5)∂
Pneumonia	1.8 (1.0, 2.6)	2.0 (1.2, 2.8)	2.0 (1.2, 2.8)	1.3 (0.5, 2.1)	0.7 (-0.05, 1.5)	7.2 (4.0, 10.4)∂
Stroke	1.8 (1.1, 2.6)	0.3 (-0.4, 0.9)	1.1 (0.4, 1.7)	0.1 (-0.6, 0.8)	0.3 (-0.4, 1.0)	3.1 (1.0, 5.3)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Cold Season = October to March. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

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Table 17. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.4 (1.1, 1.8)	0.8 (0.5, 1.1)	0.8 (0.5, 1.2)	0.4 (0.1, 0.7)	3.1 (1.8, 4.4)β
CVD	1.1 (0.6, 1.7)	0.5 (-0.03, 1.1)	0.7 (0.02, 1.3)	0.1 (-0.5, 0.7)	2.4 (0.7, 4.1)†
IHD	1.4 (0.7, 2.1)	0.3 (-0.4, 0.9)	0.9 (0.2, 1.6)	0.5 (-0.2, 1.1)	2.5 (0.3, 4.6)†
MI	1.5 (0.8, 2.2)	0.3 (-0.3, 1.0)	1.0 (0.2, 1.7)	0.4 (-0.3, 1.2)	2.6 (0.6, 4.6)†
Respiratory Disease	2.6 (1.8, 3.4)	2.0 (1.2, 2.7)	2.5 (1.8, 3.3)	0.5 (-0.2, 1.3)	7.1 (4.8, 9.4)†
COPD	3.7 (2.1, 5.3)	1.8 (0.3, 3.3)	1.4 (-0.2, 3.0)	0.4 (-1.2, 2.0)	5.5 (1.9, 5.8)δ
Pneumonia	1.8 (0.8, 2.8)	2.1 (1.1, 3.0)	2.8 (1.8, 3.7)	0.7 (-0.2, 1.7)	6.6 (3.7, 9.5)†
Stroke	1.4 (0.4, 2.3)	0.7 (-0.3, 1.6)	1.2 (0.3, 2.1)	1.0 (0.01, 1.9)	4.2 (0.4, 8.0)β

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Cold period = October to March. βCumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3. δCumulative change calculated for lag of week 1 to 2. Zeka et al., 2014

Table 18. Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the winter months‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Lag of Week 5 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality	1.8 (1.5, 2.1)	1.4 (1.0, 1.7)	1.4 (1.1, 1.7)	1.0 (0.7, 1.3)	0.8 (0.5, 1.0)	6.4 (4.8, 7.9)§
CVD	1.8 (1.3, 2.3)	1.3 (0.8, 1.8)	1.3 (0.8; 1.8)	1.2 (0.6, 1.7)	0.4 (-0.1, 0.9)	5.6 (3.5, 7.7)∂
IHD	2.1 (1.5, 2.7)	0.8 (0.2, 1.4)	1.4 (0.8, 2.0)	1.0 (0.4, 1.6)	0.5 (-0.1, 1.1)	5.3 (2.9, 7.8)∂
MI	1.9 (1.2, 2.7)	0.8 (0.1, 1.6)	1.4 (0.7, 2.1)	0.9 (0.2, 1.6)	0.7 (-0.03, 1.3)	5.1 (2.2, 8.0)∂
Respiratory Disease	2.5 (1.7, 3.2)	3.2 (2.5, 3.9)	2.6 (1.9, 3.4)	2.7 (1.9, 3.4)	1.5 (0.8, 2.2)	12.5 (8.9, 16.2)§
COPD	2.3 (1.2, 3.5)	2.8 (1.6, 3.9)	2.3 (1.2, 3.5)	2.9 (1.7, 4.0)	1.4 (0.3, 2.5)	11.7 (6.0, 17.4)§
Pneumonia	2.9 (1.8, 4.0)	3.6 (2.6, 4.7)	3.2 (2.2, 4.3)	2.5 (1.5, 3.6)	1.5 (0.5, 2.5)	13.8 (8.4, 19.1)§
Stroke	2.5 (1.5, 3.5)	1.1 (0.1, 2.1)	1.4 (0.4, 2.4)	0.8 (-0.2, 1.7)	0.8 (-0.1, 1.8)	5.0 (2.1, 8.0)†

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, week 4 for lag22-28, and week 5 for lag29-35. ‡Winter Months = December to February. §Cumulative change calculated for lag of week 1 to 5. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.

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Table 19. Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during the winter months‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Lag of Week 1 % Change (95% CI)	Lag of Week 2 % Change (95% CI)	Lag of Week 3 % Change (95% CI)	Lag of Week 4 % Change (95% CI)	Cumulative % Change (95% CI)
All-cause Mortality†	1.7 (1.3, 2.2)	1.2 (0.8, 1.7)	1.6 (1.1, 2.0)	0.4 (-0.01, 0.9)	4.5 (3.2, 5.9)
CVD†	1.9 (1.1, 2.7)	0.5 (-0.3, 1.3)	1.5 (0.7, 2.3)	0.1 (-0.7, 0.9)	3.9 (1.5, 6.3)
IHD†	2.3 (1.3, 3.2)	0.1 (-0.8, 1.0)	1.5 (0.5, 2.4)	-0.3 (-1.2, 0.6)	3.8 (1.0, 6.6)
MI†	2.2 (1.2, 3.2)	-0.02 (-1.0, 1.0)	1.5 (0.5, 2.5)	-0.2 (-1.2, 0.8)	3.7 (0.7, 6.7)
Respiratory Disease∂	2.8 (1.8, 3.9)	2.7 (1.7, 3.7)	4.3 (3.2, 5.3)	1.4 (0.4, 2.4)	11.2 (7.1, 15.3)
COPD†	3.7 (1.5, 5.8)	3.1 (1.0, 5.2)	3.9 (1.8, 6.0)	0.8 (-1.3, 2.9)	10.6 (4.2, 17.0)
Pneumonia∂	2.1 (0.8, 3.4)	2.5 (1.2, 3.7)	4.1 (2.8, 5.4)	1.5 (0.2, 2.8)	10.2 (5.0, 15.4)
Stroke†	2.0 (0.7, 3.3)	0.9 (-0.4, 2.2)	1.9 (0.6, 3.2)	0.9 (-0.4, 2.2)	4.8 (0.9, 8.8)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. ‡Winter Months = December to February. ∂Cumulative change calculated for lag of week 1 to 4. †Cumulative change calculated for lag of week 1 to 3.
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Table 20. Estimated cumulative mortality percentage change per 1⁰C decrease in maximum temperature in the Republic of Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Male and Female			All Ages	
	18-64 years % Change (95% CI)	65-74 years % Change (95% CI)	75+ years % Change (95% CI)	Male % Change (95% CI)	Female % Change (95% CI)
All-cause Mortality§	1.9 (-0.8, 4.6)	3.1 (0.8, 5.4)	4.5 (3.0, 5.9)	3.6 (2.1, 5.2)	3.7 (2.1, 5.3)
CVD∂	3.2 (-0.8, 7.2)	2.6 (-0.5, 5.8)	4.4 (2.3, 6.4)	3.5 (1.4, 5.6)	4.1 (1.7, 6.4)
IHD∂	3.0 (-1.4, 7.3)	2.5 (-1.1, 6.0)	4.0 (1.5, 6.5)	3.1 (0.7, 5.4)	3.9 (1.1, 6.7)
MI∂	3.6 (-1.7, 8.8)	2.5 (-1.6, 6.6)	4.2 (1.1, 7.2)	3.2 (0.4, 6.0)	4.2 (0.8, 7.5)
Respiratory Disease§	7.6 (-2.3, 17.5)	5.7 (-0.7, 12.1)	8.0 (4.4, 11.6)	7.5 (3.7, 11.4)	7.5 (3.6, 11.4)
COPD§	9.8 (-2.2, 21.8)	5.5 (-1.6, 12.6)	7.4 (2.3, 12.5)	6.9 (2.3, 11.5)	7.4 (1.7, 13.0)
Pneumonia§	7.3 (-7.6, 22.1)	5.6 (-4.4, 15.7)	7.4 (2.8, 12.0)	7.9 (2.9, 13.0)	6.6 (2.2, 11.0)
Stroke†	-0.4 (-7.6, 6.9)	2.8 (-2.4, 8.1)	3.7 (0.8, 6.6)	2.0 (-1.3, 5.4)	3.9 (1.1, 6.8)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1⁰C decrease in weekly mean of maximum temperature. ‡cold period = October to March. § Effect modification examined for cumulative change for lags of week 1 to 5; (∂) for cumulative change for lags of week 1 to 4; and (†) for cumulative change for lags of week 1 to 3.

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Table 21. Estimated cumulative mortality percentage change per 1⁰C decrease in maximum temperature in Northern Ireland during the cold period‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Male and Female			All Ages	
	18-64 years % Change (95% CI)	65-74 years % Change (95% CI)	75+ years % Change (95% CI)	Male % Change (95% CI)	Female % Change (95% CI)
All-cause Mortality†	2.1 (0.0, 4.3)	2.8 (1.0, 4.6)	4.1 (2.9, 5.2)	3.2 (1.3, 5.1)	3.0 (1.1, 4.8)
CVD†	2.4 (-0.6, 5.4)	2.3 (-0.1, 4.7)	3.7 (2.1, 5.2)	2.8 (0.4, 5.2)	1.9 (-0.6, 4.5)
IHD†	2.5 (-0.8, 5.7)	2.0 (-0.6, 4.7)	3.5 (1.6, 5.4)	2.6 (-0.1, 5.4)	2.5 (-0.6, 5.6)
MI†	3.1 (-0.9, 7.0)	1.9 (-1.2, 5.0)	3.6 (1.3, 5.9)	2.6 (-0.3, 5.6)	2.3 (-1.0, 5.6)
Respiratory Disease∂	6.3 (0.3, 12.3)	3.5 (-0.4, 7.4)	5.5 (3.4, 7.7)	7.2 (3.8, 10.7)	7.0 (3.9, 10.2)
COPD†	5.2 (-0.8, 11.3)	2.7 (-0.9, 6.3)	3.5 (0.9, 6.0)	5.1 (0.7, 9.5)	6.1 (1.0, 11.2)
Pneumonia∂	6.8 (-4.3, 17.9)	5.4 (-2.2, 13.0)	5.9 (2.4, 9.3)	6.4 (1.7, 11.2)	6.8 (2.9, 10.6)
Stroke†	1.9 (-7.7, 11.5)	3.2 (-3.8, 10.1)	3.9 (0.05, 7.9)	3.6 (-2.9, 10.0)	4.6 (-0.4, 9.6)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. ‡Cold period = October to March. ∂ Effect modification examined for cumulative change for lags of week 1 to 4; and (†) for cumulative change for lags of week 1 to 3.

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Table 22. Estimated cumulative mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during the winter months‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Male and Female			All Ages	
	18-64 years % Change (95% CI)	65-74 years % Change (95% CI)	75+ years % Change (95% CI)	Male % Change (95% CI)	Female % Change (95% CI)
All-cause Mortality§	3.3 (-0.3, 7.0)	5.2 (2.1, 8.3)	7.7 (5.7, 9.7)	6.1 (4.0, 8.2)	6.6 (4.4, 8.8)
CVD∂	3.9 (-1.5, 9.3)	4.8 (0.4, 9.1)	6.3 (3.5, 9.2)	5.6 (2.7, 8.5)	5.5 (2.4, 8.7)
IHD∂	3.3 (-2.6, 9.3)	4.7 (-0.1, 9.5)	6.4 (3.0, 9.7)	5.3 (2.1, 8.5)	5.4 (1.6, 9.2)
MI∂	4.0 (-3.1, 11.1)	4.0 (-1.5, 9.6)	6.1 (2.0, 10.2)	4.9 (1.1, 8.8)	5.3 (0.8, 9.9)
Respiratory Disease§	14.4 (1.8, 27.1)	10.8 (2.8, 18.8)	12.9 (8.6, 17.1)	11.6 (6.5, 16.6)	13.6 (8.5, 18.7)
COPD§	15.0 (-3.6, 33.6)	10.5 (0.04, 20.9)	11.8 (4.5, 19.1)	10.2 (2.9, 17.5)	14.0 (5.0, 22.0)
Pneumonia§	14.0 (-8.8, 36.6)	9.4 (-5.6, 24.4)	14.4 (8.5, 20.3)	14.2 (6.1, 22.2)	13.5 (6.3, 20.6)
Stroke†	2.9 (-7.3, 12.5)	4.2 (-2.9, 11.3)	5.6 (1.7, 9.4)	3.7 (-1.0, 8.4)	5.9 (2.0, 9.9)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. ‡Winter Months = December to February. § Effect modification examined for cumulative change for lags of week 1 to 5; (∂) for cumulative change for lags of week 1 to 4; and (†) for cumulative change for lags of week 1 to 3.

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Table 23. Estimated cumulative mortality percentage change per 1⁰C decrease in maximum temperature in Northern Ireland during the winter months‡ for ages ≥18 years, 1984-2007.*

Cause-specific mortality group	Male and Female			All Ages	
	18-64 years % Change (95% CI)	65-74 years % Change (95% CI)	75+ years % Change (95% CI)	Male % Change (95% CI)	Female % Change (95% CI)
All-cause Mortality†	2.7 (-0.7, 6.0)	4.5 (1.6, 7.3)	5.1 (3.3, 6.9)	4.8 (2.8, 6.8)	4.3 (2.4, 6.2)
CVD†	4.3 (-1.7, 10.3)	4.7 (-0.1, 9.6)	3.5 (0.1, 6.8)	5.1 (1.8, 8.5)	2.6 (-0.9, 6.1)
IHD†	3.6 (-3.0, 10.3)	5.2 (-0.3, 10.6)	3.1 (-0.9, 7.2)	4.4 (0.6, 8.2)	3.1 (-1.3, 7.4)
MI†	4.0 (-3.5, 11.6)	4.3 (-1.6, 10.3)	3.3 (-1.2, 7.8)	4.1 (0.02, 8.3)	3.2 (-1.3, 7.8)
Respiratory Disease∂	15.3 (0.5, 30.2)	12.8 (2.3, 23.2)	10.4 (4.9, 15.8)	9.2 (3.0, 15.4)	12.9 (7.2, 18.6)
COPD†	11.4 (-7.0, 29.7)	15.6 (2.6, 28.6)	7.8 (-2.0, 17.6)	10.4 (1.7, 19.2)	10.9 (0.7, 21.1)
Pneumonia∂	19.2 (-6.3, 44.7)	9.5 (-7.6, 26.6)	9.7 (2.4, 17.1)	7.4 (-1.1, 15.9)	11.9 (5.0, 18.8)
Stroke†	6.2 (-8.0, 20.3)	3.3 (-6.8, 13.5)	5.0 (-0.3, 10.4)	6.8 (0.2, 13.4)	3.6 (-1.5, 8.7)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction.*Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and air pressure average over 3 day lag, and day of week. % Change = estimated mortality percentage change per 1⁰C decrease in weekly mean of maximum temperature. ‡Winter Months = December to February. ∂ Effect modification examined for cumulative change for lags of week 1 to 4; and (†) for cumulative change for lags of week 1 to 3.

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Appendix 1: co-author in an international report

Fuel poverty, older people and cold weather: An all-island analysis

Authors: Patrick Goodman (DIT Kevin Street), Helen McAvoy (IPH), Noëlle Cotter (IPH), Eugene Monahan (Dublin City Council), Eimear Barrett (QUB), Stephen Browne and Ariana Zeka (Brunel University London)

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Project partners:



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Appendix 1: co-author in an international report (continued)

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Appendix 1: co-author in an international report (continued)

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CHAPTER 4

Excess Winter Mortality Comparisons between Republic of Ireland and Northern Ireland

Authors: Patrick Goodman & Stephen Browne

4.1 Introduction

It is well established that in many countries there is significantly more mortality in winter than in summer. Clearly, in some instances some of this excess winter mortality can be explained in terms of epidemics such as influenza, however there are many studies which have taken account of influenza, and still demonstrate a strong relationship between increased mortality and cold temperatures.

A study of temperature-related mortality for Dublin showed that cold temperatures were associated with increased all-cause mortality. These effects extended for 2 to 3 weeks; and were not just an immediate acute effect and were observed in all age groups with the biggest effects among older people. Each 1°C decrease in temperature was associated with a 2.6% increased total mortality over the subsequent 40 days. These effects of temperature on mortality in Dublin were similar to reports from other European studies (Goodman et al, 2004).

Gemmell et al (2000) reported that each 1°C reduction in weekly average temperature in Scotland was associated with an approximately 1% increase in total mortality, which persisted for several weeks, Donaldson and Keatinge (1997) reported that lower mean temperatures in the Republic of Ireland - East of England were associated with excess deaths from all causes. The maximum effects were observed 3 days after the cold peak and effects lasted out to 40 days. Keatinge and Donaldson (2001) reported that a 1°C decrease in temperature was associated with 3% increase in total deaths over the next 24 days in greater London. Others have also reported strong associations between increased mortality and prolonged periods of cold weather in London (Eurowinter Group, 1997; Wilkinson et al, 1999).

It is against this background that we explored winter mortality on the island of Ireland, comparing the Republic of Ireland with Northern Ireland, and comparing the winter and summer periods. A clear message from the literature is that cold weather effects can act over a prolonged time period, and that it is not just one or two cold days that effect people. It seems that long periods of cold weather appear to weaken those who are susceptible, and that if the cold weather continues they may get progressively weaker and eventually die, while if temperatures rise they may recover.

Housing conditions and the ability to keep warm plays a key role in whether old people can survive the winter and this is taken in conjunction with their general health to begin with.

Appendix 1: co-author in an international report (continued)

Causes of death

Excess winter mortality is not normally recorded as being from hypothermia, but cold weather interacts to trigger deaths from existing cardiovascular disease (CVD) and/or respiratory conditions.

These temporal associations with mortality vary with cause of death. In Dublin, Goodman et al (2004) reported an immediate effect of cold on cardiovascular mortality that decreased over the subsequent 3 weeks. They reported a net effect of each 1°C decrease in temperature associated with a 2.5% increase in cardiovascular mortality over the succeeding 40 days, while in the Netherlands (Huynen et al, 2001) reported a 1.7% increase in cardiovascular mortality in the 30 days after each 1°C temperature decrease. In Scotland, ischaemic heart disease mortality increased by around 1% in the week of, and the week after, a 1°C decrease in temperature (Gemmell et al, 2000). Winter deaths in London due to coronary thrombosis were reported to peak about 2 days after a cold spell (Keatinge, 2002).

In the US (Braga et al, 2002) found that both high and low temperatures were associated with increased cardiovascular mortality. The effect of high temperatures on cardiovascular deaths was restricted to the day of, and the day after the heat events, whereas the effects of cold temperatures persisted for several days.

When one considers respiratory deaths, Goodman et al (2004) reported for Dublin that in the 40 days after each decrease of 1°C in temperature, respiratory deaths increased by 6.7%. In the Netherlands, a 5.2% increase in respiratory deaths after each 1°C decrease in average monthly temperature was reported (Huynen et al, 2001). The cold effects on respiratory mortality were strongest 2 to 4 weeks after the cold event. Winter respiratory deaths were reported to peak about 12 days after a cold spell (Keatinge, 2002). In Scotland respiratory deaths increased by about 1% 1 to 2 weeks after a decrease of 1°C in weekly mean temperature (Gemmell et al, 2000).

General practitioner visits by the older people for respiratory disease in London were found to rise by 10.5% for each 1°C drop in temperature (Hajat and Haines, 2002). In summary, warm temperatures have an immediate effect on mortality, specifically cardiovascular mortality. Cold temperatures have strong effects on both cardiovascular and respiratory mortality that can persist from days to weeks.

4.2 Methods

We obtained daily mortality data for Northern Ireland from the General Registry Office of the Northern Ireland Statistics and Research Agency and for the Republic of Ireland from the Central Statistics Office. The data was aggregated to produce weekly, monthly and yearly deaths. We further segregated the data to produce all cardiovascular deaths (ICD-9 codes 390-429, ICD-10 codes I01-I52), all respiratory deaths (ICD-9 codes 460-519, ICD-10 codes J0-J99) and deaths from stroke (ICD-9 codes 430-438 and ICD-10 codes I60-I69). We also included total (non-accidental) deaths (ICD-9 codes 001-799, ICD-10 codes A00-R99). We analysed the data for age groups (65-74 years old, 75-84 years old and 85 years and older). These particular causes of death were selected as they had previously been shown in other studies as demonstrating strong seasonal trends.

Appendix 1: co-author in an international report (continued)

In order to compare mortality between the Republic of Ireland and Northern Ireland we considered the Census population data for each country and calculated the specific death rates for age and gender, using the population numbers in each category and subcategory in the analysis.

For the purposes of this report we have concentrated on presenting data for each of the census years over the 20 year period, that is 1986, 1991, 1996, 2002, 2006.

4.3 Results

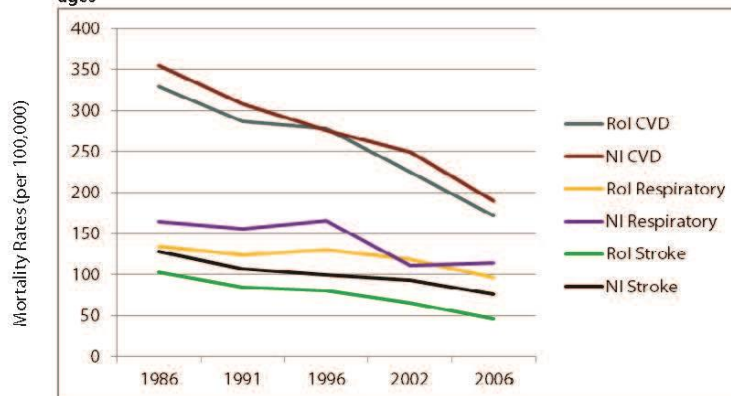
Comparison of mortality rates between Northern Ireland and the Republic of Ireland over time, by causes and age groups

Although the population of both Northern Ireland and the Republic of Ireland have increased since 1986, there has been a general decline across the annual mortality rates for all ages from cardiovascular disease (CVD), respiratory disease and stroke in the Republic of Ireland from 1986 to 2006 (see Figure 4.1). What is of particular note is that the rates in Northern Ireland are consistently higher for all causes.

A key observation from Figure 4.1 is that there is a general downward trend in mortality rates over the study period, this reflects the improvement in the overall health status and health care over this time, in spite of the rising population. The total population of the Republic of Ireland has increased by 19.7% from 3,540,643 in 1986 to 4,239,848 in 2006. The male population of the Republic of Ireland has also increased by 19.9% from 1,769,698 in 1986 to 2,121,082 by 2006 whereas the female population has increased by 19.6% from 1,770,953 to 2,118,677 over the same time period.

In Northern Ireland, the total population has increased by 10% from 1,566,800 in 1986 to 1,741,619 in 2006. The male population of Northern Ireland has increased by 11.1% from 768,400 to 853,404 over the 20-year period while the female population has increased by 10.1% from 798,400 to 888,215 over the same period (see Figure 4.1).

Figure 4.1: Annual Mortality Rates for the Republic of Ireland (RoI) and Northern Ireland (NI) for all ages



Appendix 1: co-author in an international report (continued)

4.4 Excess Winter Mortality Results

This section presents an analysis of the winter mortality, comparing rates with summer and comparing Northern Ireland and the Republic of Ireland. As part of this study, summer was defined as the months of June to August inclusive while winter was defined as December, January and February. The data for the summer of one year was analysed with the data for the following winter, that is summer 1986 and winter 1986/7 and this was repeated for each of the census years in this study.

Figure 4.2: Comparison of Summer and Winter CVD Mortality Rates for Republic of Ireland and Northern Ireland (all ages)

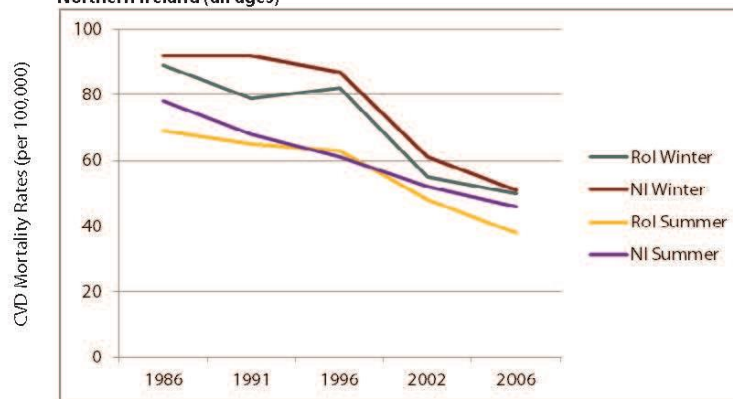


Figure 4.2 illustrates the general downward trend in cardiovascular mortality over time, which, as already mentioned is partly due to improvements in health care. The graph also clearly illustrates the differences between winter and summer mortality rates. Over time there is a slight convergence but the seasonal differences are still quite marked, highlighting the effect of cold weather on mortality patterns.

When one considers the differences between Northern Ireland and the Republic of Ireland, the rates in the Republic of Ireland are lower, both for summer and winter, however these are seen to converge closer to each other over time.

Appendix 1: co-author in an international report (continued)

Figure 4.3: Comparison of Summer and Winter Respiratory Mortality Rates for Republic of Ireland and Northern Ireland (all ages)

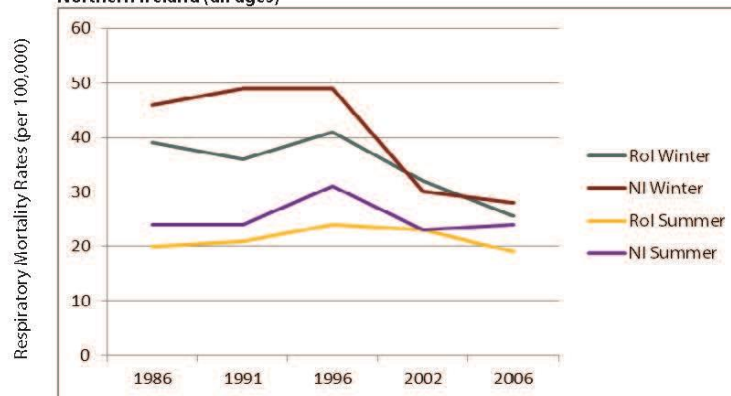
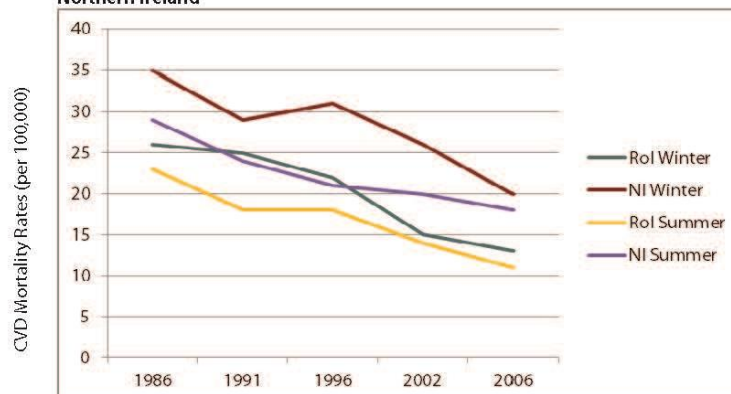


Figure 4.3 illustrates the comparison between the summer and winter mortality rates from respiratory disease in the Republic of Ireland and Northern Ireland. We observe significantly higher rates in Northern Ireland compared to the Republic of Ireland, particularly for winter, some of this is possibly due to coding differences for respiratory deaths. But it does consistently indicate higher rates in Northern Ireland than the Republic of Ireland, but as with cardiovascular disease, the rates are seen to decrease overtime, and again there is evidence of convergence with time between the two regions. The graph clearly illustrates the excess winter mortality for these causes compared with summer.

Figure 4.4: Comparison Summer and Winter Mortality Rates from Stroke for Republic of Ireland and Northern Ireland



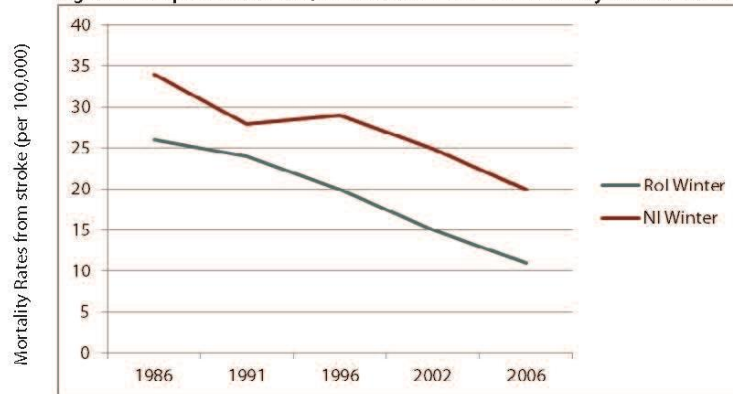
When we consider mortality from stroke, (Figure 4.4) we again see a strong downward trend over time, and we also see the strong winter/summer differences, with higher mortality in winter, again reflecting the excess winter mortality phenomena. A key issue is that the rates in Northern Ireland are considerable higher, and in fact the summer rates in

Appendix 1: co-author in an international report (continued)

Northern Ireland are more like the winter rates in the Republic of Ireland. These differences may well be real differences in the way health care is provided, although systematic differences in the coding of deaths may also account for some of the differences.

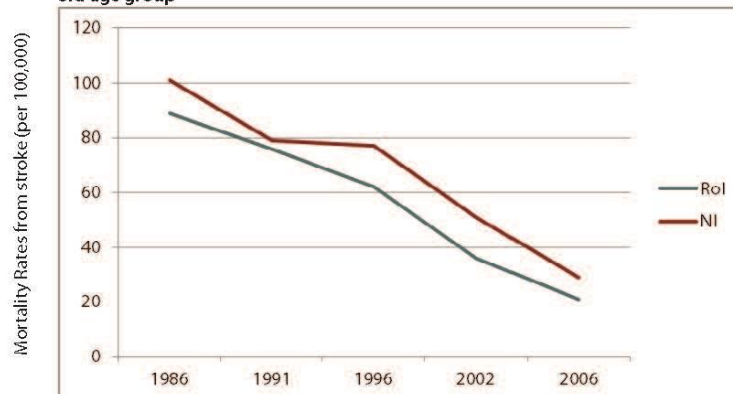
The following graphs focus on the winter mortality rates. Stroke deaths have been selected for illustration purposes, as these showed a distinct difference between the two jurisdictions.

Figure 4.5: Republic of Ireland/Northern Ireland Winter Mortality Rates from Stroke



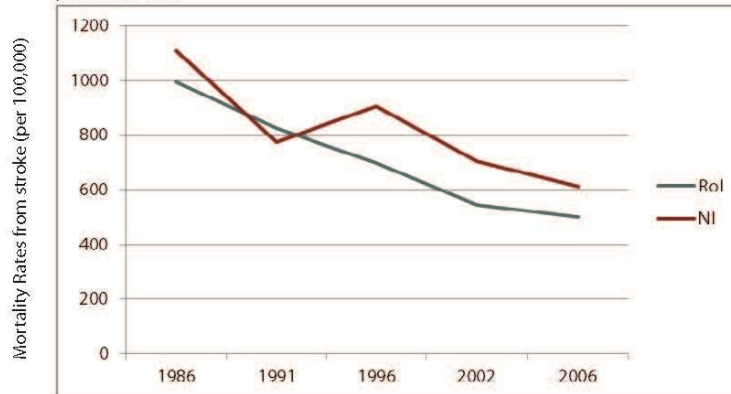
The following three graphs illustrate the winter stroke deaths, by age groups, 65-74, 75-84 and 85 years and older.

Figure 4.6: Winter Mortality Rates from Stroke in Republic of Ireland and Northern Ireland 65-74 year old age group



Appendix 1: co-author in an international report (continued)

Figure 4.7: Winter Mortality Rates from Stroke in Republic of Ireland and Northern Ireland age 85 years and over



When age of death is considered, we still see the big differences between Northern Ireland and the Republic of Ireland, with rates in Northern Ireland being consistently higher than the Republic of Ireland, across all the age groups.

Obviously death rates among older ageing groups (85+ years) increase significantly, and these are also reflected in the overall deaths rates by cause of death.

4.5 Discussion and Key Findings

Although the populations of the Republic of Ireland and Northern Ireland have increased in the last 20 years, mortality rates have been falling over the same period. In general, Northern Ireland experienced higher mortality from CVD, respiratory, and mortality rates from stroke, in all ages. This is also similar when one considers the various age groups. What is seen is that the mortality rates from all of the selected categories are seen to converge closer together with time.

Some of the differences observed between Northern Ireland and the Republic of Ireland might be explained by systematic differences in the coding of deaths however this would not explain all of the observed differences. It is quite clear that rates for all of these causes have been higher in Northern Ireland in winter compared to the Republic of Ireland, and there may be a myriad of factors giving rise to this, for example, diet, health care, housing conditions. We have observed that these differences have narrowed with time.

Key Findings

- Mortality has decreased even though the populations have increased and are also ageing. Mortality rates have dropped significantly over the past 20 years.
- For the mortality categories chosen, winter mortality rates are significantly higher than the summer rates for the same causes.

Appendix 1: co-author in an international report (continued)

- Mortality rates were higher in Northern Ireland compared to the Republic of Ireland, but the differences have narrowed significantly over time.
- Northern Ireland experienced a higher mortality rate from CVD, respiratory and stroke than the Republic of Ireland in all ages, though the differences have narrowed with time.
- Excess winter mortality for cardiovascular, respiratory and stroke among older people was observed for all years and is present in both Northern Ireland and the Republic of Ireland.

Additional work

This work has set the foundations for ongoing detailed research into climate and health in this age group. Now that the datasets have been compiled, it is planned to conduct further analysis comparing Northern Ireland and the Republic of Ireland. We will use a time series approach, and also investigate the lag structures between exposure to cold temperatures and mortality. The support of CARDI will be acknowledged in all ongoing work.

Appendix 2: co-author in an academic research paper published in the Environmental Health journal

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RESEARCH

Open Access

The association of cold weather and all-cause and cause-specific mortality in the island of Ireland between 1984 and 2007

Ariana Zeka^{1*}, Stephen Browne¹, Helen McAvoy² and Patrick Goodman³

Abstract

Background: This study aimed to assess the relationship between cold temperature and daily mortality in the Republic of Ireland (ROI) and Northern Ireland (NI), and to explore any differences in the population responses between the two jurisdictions.

Methods: A time-stratified case-crossover approach was used to examine this relationship in two adult national populations, between 1984 and 2007. Daily mortality risk was examined in association with exposure to daily maximum temperatures on the same day and up to 6 weeks preceding death, during the winter (December-February) and an extended cold period (October-March), using distributed lag models. Model stratification by age and gender assessed for modification of the cold weather-mortality relationship.

Results: In the ROI, the impact of cold weather in winter persisted up to 35 days, with a cumulative mortality increase for all-causes of 6.4% (95% CI = 4.8%-7.9%) in relation to every 1°C drop in daily maximum temperature, similar increases for cardiovascular disease (CVD) and stroke, and twice as much for respiratory causes. In NI, these associations were less pronounced for CVD causes, and overall extended up to 28 days. Effects of cold weather on mortality increased with age in both jurisdictions, and some suggestive gender differences were observed.

Conclusions: The study findings indicated strong cold weather-mortality associations in the island of Ireland; these effects were less persistent, and for CVD mortality, smaller in NI than in the ROI. Together with suggestive differences in associations by age and gender between the two Irish jurisdictions, the findings suggest potential contribution of underlying societal differences, and require further exploration. The evidence provided here will hope to contribute to the current efforts to modify fuel policy and reduce winter mortality in Ireland.

Keywords: Cold weather, Case-crossover, Cardiovascular, Distributed lags, Mortality, Respiratory, Stroke

Background

The impacts of cold weather on human health are increasingly being evidenced by epidemiologic studies, contributing to a wide range of public health outcomes including increased mortality from cardiovascular, cerebrovascular and respiratory diseases [1-3]. Under the influences of global climate change, both mean temperature and temperature variability are expected to increase globally, likely affecting the increasing frequency of weather extremes [4,5]. Recent record low temperatures in Northern Europe and the United States highlight the potential

health and societal impacts of extreme winter weather, despite the rise in global average temperatures [3,6]. The large death toll and the disruption associated with the cold weather in Europe in the winter of 2005–2006 was a timely reminder of how poorly prepared many populations were to the dangers of extreme cold temperatures [7].

Although there has been a general trend of rising average temperatures in Ireland over the past 30 years, the island has witnessed extreme cold weather events over the same period [8,9]. Taking into consideration the differences in underlying population health, public policies targeted at preventing winter mortality, health care provision, and socioeconomic and demographic construct of the two Irish

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Appendix 2: co-author in an academic research paper published in the Environmental Health journal (continued)

jurisdictions [10-12], the health impacts of cold weather could potentially differ.

It is therefore important to understand the magnitude and geographic differences of the cold weather-health relationship on the island of Ireland in order to inform public policies aimed at improvement of population health, and targeting of vulnerable groups during periods of cold weather. This study aimed to assess the cold temperature and all-cause and cause-specific mortality relationship in the Republic of Ireland (ROI) and Northern Ireland (NI), and to assess for modification of this relationship by age and gender.

Methods

Mortality

Individual daily deaths for ages ≥ 18 years were obtained from the Irish Central Statistics Office for data in the ROI, and Northern Ireland Social Research Agency for data in NI for the period of January 1st 1984 and December 31st 2007. International Classification of Disease-9 (ICD-9) codes were used up to 2006, and ICD-10 codes from 2007. Non-accidental deaths were used for this study (ICD-9 codes 001-799/ICD-10 codes A00-R99), further categorised to primary cause-specific mortality for cardiovascular disease (CVD) (390-429; I01-I52), ischaemic heart disease (IHD) (410-414, 429.2; I20-I52), myocardial infarction (MI) (410; I21-I22), respiratory disease (460-519; J0-J99), pneumonia (480-486; J12-J18), chronic obstructive pulmonary disease (COPD) (490-492, 494-496; J40-J44, J47), and stroke (430-438; I60-I69).

Weather data

Full time-series weather data for the study period were obtained from Met Eireann, for ten weather stations in the ROI; and from the United Kingdom Meteorological Office for six weather stations in NI. The data included daily maximum, minimum, and mean temperatures, relative humidity and atmospheric pressure, and were merged on daily mortality data by county, based on geographical proximity to weather stations.

Statistical analyses

A time-stratified case-crossover approach was applied to assess the associations between cold weather and daily mortality in each of the two Irish jurisdictions. The case-crossover design has been originally developed and used in air pollution studies, and has been extensively described elsewhere [13-15]. Briefly, the approach is a variant of the case-control study, comparing each person's exposure at the time of death (case time) with that person's exposure in other times (control times) [13]. A time-stratified approach is used to select control days, with the day of death chosen as the case day, and controls chosen as all other days, the same day of the week, in the same month and

year as the case day, leaving two days between each control to eliminate any serial correlation [14,15]. An advantage of this design is that, if control days are chosen close in time to the day of death, there is no confounding by slowly varying personal characteristics, and even very strong confounding by season and time trend can be removed [16-18]. Conditional logistic regression was applied to matched pairs to compare the different characteristics between the case day and its control days [13]. The choice of the modeling approach was determined after data were tested that model assumptions were met, and no important data overdispersion was present [19].

Definition of seasons

Data were analyzed for the winter season (December-February) and an extended cold period (October-March). To investigate whether the observed cold weather-mortality effects were not just confined to winter months, separate analyses were also carried out for the other months in the extended cold period (October, November, and March). Cold weather-related mortality increases were observed during the extended cold period; however these associations were weaker and less persistent than those observed in winter, and will not be discussed further.

Temperature metrics

Different temperature definitions have been used in literature with no uniform criteria used to identify the best cold weather exposure metric [20,21]. In this study, daily maximum, mean and minimum temperatures were tested as exposure metrics in the models. Strongest mortality associations were obtained with daily maximum temperature, with only small differences between this and associations with mean temperature; these were slightly greater than those observed for minimum temperature. It was, therefore, decided to present results only for maximum temperature. To assess the impact of temperature variability on mortality, associations with temperature differences between daily maximum and minimum temperature, daily maximum and mean temperature, and weekly mean maximum and minimum temperature were examined as independent variables in the models. None of these associations were statistically important, and thus are not presented here.

Definition of exposure variables

Daily mortality in association with exposure to temperatures on the same day of the death (lag0) up to 6 weeks prior to the death (lag1-42 days) was examined. Weekly means of daily maximum temperatures were calculated for each of the 6 weeks, for lag1-7, 8-14, 15-21, 22-28, 29-35, and 36-42 days. Distributed lag models included all weekly lags, with lag0 included as an independent variable. This model is a way to estimate unbiased time

Appendix 2: co-author in an academic research paper published in the Environmental Health journal (continued)

trends of the exposure-response relation, by controlling for confounding in temperature-mortality associations in one lag structure by exposure to cold temperature in other lags [17]. Models were also tested with a finer definition of lag structure (means of lag1-2, 3-5, 6-9, 10-14, 15-21, 22-28 and 29-35 days) to examine acute, medium and longer term effects of temperatures. However, the models were more efficient with fewer lag structures and overall results were similar. All models included 'day of the week' as an indicator variable, with Monday as the reference, relative humidity and atmospheric pressure averaged over 3 days: the day of death and two days prior. No important contributions of relative humidity and atmospheric pressure were found in other lag structures.

No associations were observed between any mortality cause and temperature in week 6 prior to death (lag35-42 days) in both jurisdictions. Important associations were observed with temperatures up to 35 days before death for the ROI, and up to 28 days for NI during winter, and only those were presented here.

Cumulative mortality increase estimate calculation

Estimates for important associations between daily mortality and lags of weekly average of maximum temperature prior to death were used to calculate cumulative estimates of mortality increases by summing the coefficients. Cumulative estimates did not include the association of mortality with temperature on the same day (lag0). This association is consistent with previous studies that assessed the cold weather-mortality relationship [1,22], where lag0 was positive and potentially suggestive of warm temperature effects. The overall cumulative estimate variance was computed using previously described algorithms [23].

Modifying variables

The modification of the temperature-mortality relationship was examined by stratifying the models by gender, and age in the following groups: $\geq 18-64$, $\geq 65-74$, and ≥ 75 years. Statistically important differences between cumulative estimates of strata of a potential modifier were tested by calculating the 95% confidence interval of this difference (95% CI) [24]. It is also possible that the response of the two populations to the cold temperatures has changed over time. To understand long term patterns of the cold weather-mortality association, additional analyses were carried out stratified for different time periods. In these analyses, some differences over time, with effects slightly diminishing in more recent years, were observed for both jurisdictions (data not shown).

The study did not consider adjustment for air pollution; these data were also inconsistent across the Island for the study period. Current practice in epidemiologic studies examining the weather and health association is to automatically adjust for air pollution, if information on this is

available. In a recent article, Buckley et al. indicated that there is no known mechanism by which air pollution confounds the cold temperature and mortality (health) relationship [25]. In support of this rationale, previous epidemiologic studies show little or no influence of air pollution on the cold weather-mortality relationship [1-3,22,26-28]. This evidence emphasizes the robustness of our study findings, which are very important from a public policy perspective.

Results are presented as percentage (%) change in mortality per 1°C decrease in weekly average of daily maximum temperature.

Results

From the 24 years of the study data, there were a total of 709,110 non-accidental deaths in the ROI, and 347,936 in NI (Table 1). Of these deaths in the ROI, 33% were from CVD causes, 15% from respiratory diseases, and 9% from stroke, with NI showing a similar distribution. In both jurisdictions, more males died amongst ages ≥ 18 and 74 years; female deaths were greater in the ≥ 75 years age group. More than half of the deaths occurred in the ≥ 75 years old.

Overall, on average, temperatures in NI in winter were 1°C less than in the ROI, a trend which was reflected across all temperature metrics (Table 2).

Mortality-temperature associations for the winter season in the ROI are presented in Table 3. All-cause mortality showed the greatest increase associated with temperatures in the preceding week to death; the impact of cold temperature on mortality slightly weakened, but lasted up to 5 weeks prior to death. Similar associations were observed for CVD mortality; however, effects were seen up to the preceding 4 weeks. Respiratory mortality increases were strongest in relation to temperatures 2 weeks prior to death, and remained strong in weeks 3 to 4, extending, but slightly weakening into week 5. COPD and pneumonia mortality showed a similar pattern. Stroke mortality increases were observed in association with temperatures up to 3 weeks preceding death.

In the ROI, cumulative increases in mortality were calculated over the 5 week period for all-cause and respiratory disease; for a 4-week period for CVD mortality; and over the preceding 3 weeks for stroke. The cumulative increase for all-cause mortality was 6.4% (95% confidence interval-CI = 4.8%-7.9%). Similar cumulative increases were observed for CVD, and stroke mortality; increases for respiratory mortality were twice as large.

Table 4 presents the temperature-mortality associations during the winter months in NI. All-cause mortality showed important increases up to 3 weeks prior to death. The increases for CVD and stroke mortality were strongest in weeks 1 and 3. Respiratory mortality increased for cold temperatures 1 to 4 weeks prior, with similar associations

Appendix 2: co-author in an academic research paper published in the Environmental Health journal (continued)

Table 1 Total number of deaths stratified by age and gender in the Republic of Ireland and Northern Ireland between 1984 and 2007

Cause of death	Gender	Republic of Ireland						Northern Ireland									
		All year			Cold period			All year			Cold period						
		All ages	18-64 yr.	65-74 yr.	75+ yr.	All ages	18-64 yr.	65-74 yr.	75+ yr.	All ages	18-64 yr.	65-74 yr.	75+ yr.				
All-cause Mortality	Male	367548	82345	100866	184337	196918	39411	53776	93136	168304	40129	46253	81922	89471	19248	24425	40922
	Female	341562	52572	65219	223771	184181	24471	34704	116771	179632	26934	33587	11911	96612	12723	17801	62179
CVD	Male	127771	28183	37217	62371	68745	14677	20026	31487	57434	13868	17520	26046	30595	7168	9328	12939
	Female	103469	8220	18991	76258	56196	4312	10210	39949	51892	4897	10566	36429	28140	2684	5738	18798
IHD	Male	101986	23909	31549	46472	54697	12450	16910	23309	44975	11844	14243	18888	23990	6144	7608	9328
	Female	72103	5997	14898	51206	39066	3167	7989	26636	34911	3581	7889	23441	18932	1980	4243	12061
MI	Male	71695	16429	23351	31912	38526	8551	12516	16001	37543	9046	12208	16289	20063	4693	6515	8058
	Female	49351	4235	11189	33925	26868	2246	6058	17638	30452	2963	7129	20360	16602	1641	3853	10533
Respiratory Disease	Male	54019	5348	12151	36520	31263	2858	7169	19948	26398	3058	5634	17706	15217	1550	3264	9635
	Female	52180	3601	7966	40613	30680	2024	4736	22933	31651	2357	4123	25171	18605	1193	2418	14405
COPD	Male	24523	2228	6913	15371	14435	1343	4144	8360	7765	920	2357	4488	4465	568	1358	2344
	Female	16115	1422	4140	10546	9729	889	2570	5892	5627	736	1628	3263	3379	458	996	1794
Pneumonia	Male	21613	1556	3443	16470	12405	868	2018	9042	14113	1081	2193	10839	8163	564	1286	6010
	Female	27636	1029	2559	23933	16051	614	1458	13580	21843	819	1758	19266	12818	416	1015	11115
Stroke	Male	28235	3637	6932	17666	15273	1915	3719	9033	14781	1951	3552	9278	7865	1005	1866	4662
	Female	38902	2978	5834	30090	21183	1520	3139	15877	24760	1696	3468	19596	13332	866	1838	10278

Abbreviations: COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction, total = male and female, and yr. = years.

Appendix 2: co-author in an academic research paper published in the Environmental Health journal (continued)

Table 2 Weather descriptives for the Republic of Ireland and Northern Ireland between 1984 and 2007

Season	Temperature*	Republic of Ireland				Northern Ireland					
		Mean ± SD	Percentiles				Mean ± SD	Percentiles			
			99th	90th	10th	1st		99th	90th	10th	1st
All year	Mean	9.7 ± 4.4	19.0	15.4	4.1	0.4	9.1 ± 4.4	18.6	15.2	3.4	0.0
	Minimum	6.3 ± 4.4	15.2	12.1	0.6	-3.5	5.9 ± 4.5	15.0	11.9	0.0	-3.9
	Maximum	13.0 ± 4.8	24.1	19.4	7.0	3.1	12.4 ± 4.9	23.5	18.9	6.1	2.5
Summer [§]	Mean	14.7 ± 2.3	20.5	17.8	11.9	9.4	14.4 ± 2.4	20.1	17.5	11.4	8.9
	Minimum	10.9 ± 2.6	16.5	14.0	7.6	4.3	10.6 ± 2.7	16.2	13.9	7.1	3.6
	Maximum	18.6 ± 2.8	26.4	22.3	15.2	12.6	18.1 ± 2.8	25.7	21.9	14.7	12.0
Winter Months [†]	Mean	5.8 ± 2.9	11.8	9.5	2.0	-1.1	4.9 ± 2.7	10.7	8.3	1.5	-1.4
	Minimum	3.1 ± 3.3	10.3	7.4	-1.2	-4.9	2.2 ± 3.2	9.5	6.4	-1.8	-5.6
	Maximum	8.6 ± 2.8	13.9	12.0	4.8	1.5	7.6 ± 2.7	13.2	11.1	4.0	1.0
Cold Period [‡]	Mean	7.0 ± 3.2	14.4	11.1	2.9	-0.4	6.3 ± 3.2	14.0	10.5	2.3	-0.8
	Minimum	4.1 ± 3.7	16.0	8.8	-0.5	-4.4	3.4 ± 3.6	12.0	8.3	-1.0	-4.9
	Maximum	10.0 ± 3.2	17.4	14.0	5.7	2.2	9.1 ± 3.3	16.7	13.2	4.9	1.7

Abbreviations: SD = standard deviation, *in degrees Celsius (°C), [§]Summer = June to August, [†]Winter Months = December to February, and [‡]Cold Period = October to March.

observed for pneumonia. COPD mortality was associated with cold temperatures up to 3 weeks prior.

Cumulative mortality increases were calculated for associations with cold temperatures in the 4 weeks before death for all respiratory disease and pneumonia. For all other causes important effects were only seen up to the preceding week 3 and cumulative increases were only calculated over this period. Cumulative mortality increase for all-cause was 4.5% (95% CI = 3.2%-5.9%), for CVD 3.9% (95% CI = 1.5%-6.3%), respiratory disease 11.2% (95% CI = 7.1%-15.3%), and stroke 4.8% (95% CI = 0.9%-8.8%).

Some differences by age and gender in the cold weather-mortality associations were observed in both jurisdictions; however, overall these differences were not statistically important. Mortality increases in the ROI (Table 5) were mainly observed amongst ≥65 years old, and increased with age for all-cause and CVD. Stroke mortality increases were mainly amongst ≥75 years old, and females. No gender differences were observed for other mortality causes. In NI (Table 6), most of the cold weather-mortality impacts on all-cause and CVD were observed amongst ages ≥65 years; CVD and

Table 3 Estimated mortality percentage change per 1°C decrease in maximum temperature in the Republic of Ireland during winter[‡] for ages ≥18 years, 1984–2007*

	Lag of Week 1	Lag of Week 2	Lag of Week 3	Lag of Week 4	Lag of Week 5	Cumulative
	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)
All-cause Mortality	1.8 (1.5, 2.1)	1.4 (1.1, 1.7)	1.4 (1.1, 1.7)	1.0 (0.7, 1.3)	0.8 (0.5, 1.0)	6.4 (4.8, 7.9) [§]
CVD	1.8 (1.3, 2.3)	1.3 (0.8, 1.8)	1.3 (0.8, 1.8)	1.2 (0.6, 1.7)	0.4 (-0.1, 0.9)	5.6 (3.5, 7.7) [§]
IHD	2.1 (1.5, 2.7)	0.8 (0.2, 1.4)	1.4 (0.8, 2.0)	1.0 (0.4, 1.6)	0.5 (-0.1, 1.1)	5.3 (2.9, 7.8) [§]
MI	1.9 (1.2, 2.7)	0.8 (0.1, 1.6)	1.4 (0.7, 2.1)	0.9 (0.2, 1.6)	0.7 (-0.03, 1.3)	5.1 (2.2, 8.0) [§]
Respiratory Disease	2.5 (1.7, 3.2)	3.2 (2.5, 3.9)	2.6 (1.9, 3.4)	2.7 (1.9, 3.4)	1.5 (0.8, 2.2)	12.5 (8.9, 16.2) [§]
COPD	2.3 (1.2, 3.5)	2.8 (1.6, 3.9)	2.3 (1.2, 3.5)	2.9 (1.7, 4.0)	1.4 (0.3, 2.5)	11.7 (6.0, 17.4) [§]
Pneumonia	2.9 (1.8, 4.0)	3.6 (2.6, 4.7)	3.2 (2.2, 4.3)	2.5 (1.5, 3.6)	1.5 (0.5, 2.5)	13.8 (8.4, 19.1) [§]
Stroke	2.5 (1.5, 3.5)	1.1 (0.1, 2.1)	1.4 (0.4, 2.4)	0.8 (-0.2, 1.7)	0.8 (-0.1, 1.8)	5.0 (2.1, 8.0) [†]

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and atmospheric pressure averaged over 3 days lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag⁻¹, week 2 for lag⁻², week 3 for lag⁻³, week 4 for lag⁻⁴, week 5 for lag⁻⁵. [‡]Winter Months = December to February. [§]Cumulative change calculated for lag of week 1 to 5. [†]Cumulative change calculated for lag of week 1 to 3.

Appendix 2: co-author in an academic research paper published in the Environmental Health journal (continued)

Table 4 Estimated mortality percentage change per 1°C decrease in maximum temperature in Northern Ireland during winter[‡] for ages ≥18 years, 1984–2007*

	Lag of Week 1	Lag of Week 2	Lag of Week 3	Lag of Week 4	Cumulative
	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)
All-cause Mortality	1.7 (1.3, 2.2)	1.2 (0.8, 1.7)	1.6 (1.1, 2.0)	0.4 (-0.01, 0.9)	4.5 (3.2, 5.9) [†]
CVD	1.9 (1.1, 2.7)	0.5 (-0.3, 1.3)	1.5 (0.7, 2.3)	0.1 (-0.7, 0.9)	3.9 (1.5, 6.3) [†]
IHD	2.3 (1.3, 3.2)	0.1 (-0.8, 1.0)	1.5 (0.5, 2.4)	-0.3 (-1.2, 0.6)	3.8 (1.0, 6.6) [†]
MI	2.2 (1.2, 3.2)	-0.02 (-1.0, 1.0)	1.5 (0.5, 2.5)	-0.2 (-1.2, 0.8)	3.7 (0.7, 6.7) [†]
Respiratory Disease	2.8 (1.8, 3.9)	2.7 (1.7, 3.7)	4.3 (3.2, 5.3)	1.4 (0.4, 2.4)	11.2 (7.1, 15.3) [‡]
COPD	3.7 (1.5, 5.8)	3.1 (1.0, 5.2)	3.9 (1.8, 6.0)	0.8 (-1.3, 2.9)	10.6 (4.2, 17.0) [†]
Pneumonia	2.1 (0.8, 3.4)	2.5 (1.2, 3.7)	4.1 (2.8, 5.4)	1.5 (0.2, 2.8)	10.2 (5.0, 15.4) [‡]
Stroke	2.0 (0.7, 3.3)	0.9 (-0.4, 2.2)	1.9 (0.6, 3.2)	0.9 (-0.4, 2.2)	4.8 (0.9, 8.8) [†]

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and atmospheric pressure averaged over 3 days lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. Week 1 corresponds to the mean of daily maximum temperature for lag1-7, week 2 for lag8-14, week 3 for lag15-21, and week 4 for lag22-28. [‡]Winter Months = December to February. [†]Cumulative change calculated for lag of week 1 to 4. [‡]Cumulative change calculated for lag of week 1 to 3.

stroke mortality increases were only observed amongst males.

Discussion

This study observed strong associations between exposure to cold weather temperatures and mortality in two adult populations, in two Irish jurisdictions over a period of 24 years. Effects of cold weather were overall less persistent in NI than in the ROI. For most associations similar mortality patterns were observed for both jurisdictions. All-cause mortality associations were strongest in the week before death, weakening but extending up to 3 weeks in NI and 5 weeks in the ROI. A similar pattern was observed for CVD mortality, but effects were smaller and less persistent in NI than in the ROI. Cold weather up to 5 weeks before death in the ROI and up to 4 weeks in NI was associated with increases in all respiratory mortality;

these increases were more extended and larger than for any other mortality group and cumulative increases were comparable in both jurisdictions, also consistent with findings of previous studies [1,2,22,29]. Stroke mortality increases were seen for exposures up to 3 weeks prior to death, and associations were comparable in both jurisdictions. Overall the impacts of cold temperature on mortality were considerably higher and more persistent in winter, although some effects were still detectable in the other months of the extended cold period.

Different temperature metrics were examined in this study, and the strongest associations were observed for maximum temperature. These findings are in agreement with recent studies which suggest that maximum temperature is more likely to capture days that are consistently cold and extreme cold days [30,31].

Table 5 Estimated cumulative mortality percentage change per 1°C decrease in maximum temperature by age and gender groups, in the Republic of Ireland during winter[‡] for ages ≥18 years, 1984–2007*

	Male and Female			All Ages	
	18-64 years	65-74 years	75+ years	Male	Female
	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)
All-cause Mortality [§]	3.3 (-0.3, 7.0)	5.2 (2.1, 8.3)	7.7 (5.7, 9.7)	6.1 (4.0, 8.2)	6.6 (4.4, 8.8)
CVD [§]	3.9 (-1.5, 9.3)	4.8 (0.4, 9.1)	6.3 (3.5, 9.2)	5.6 (2.7, 8.5)	5.5 (2.4, 8.7)
IHD [§]	3.3 (-2.6, 9.3)	4.7 (-0.1, 9.5)	6.4 (3.0, 9.7)	5.3 (2.1, 8.5)	5.4 (1.6, 9.2)
MI [§]	4.0 (-3.1, 11.1)	4.0 (-1.5, 9.6)	6.1 (2.0, 10.2)	4.9 (1.1, 8.8)	5.3 (0.8, 9.9)
Respiratory Disease [§]	14.4 (1.8, 27.1)	10.8 (2.8, 18.8)	12.9 (8.6, 17.1)	11.6 (6.5, 16.6)	13.6 (8.5, 18.7)
COPD [§]	15.0 (-3.6, 33.6)	10.5 (0.04, 20.9)	11.8 (4.5, 19.1)	10.2 (2.9, 17.5)	14.0 (5.0, 23.0)
Pneumonia [§]	14.0 (-8.8, 36.6)	9.4 (-5.6, 24.4)	14.4 (8.5, 20.3)	14.2 (6.1, 22.2)	13.5 (6.3, 20.6)
Stroke [†]	2.6 (-7.3, 12.5)	4.2 (-2.9, 11.3)	5.6 (1.7, 9.4)	3.7 (-1.0, 8.4)	5.9 (2.0, 9.9)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and atmospheric pressure averaged over 3 days lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. [‡]Winter Months = December to February. [§]Effect modification examined for cumulative change for lags of week 1 to 5; (†) for cumulative change for lags of week 1 to 4; and (‡) for cumulative change for lags of week 1 to 3.

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Table 6 Estimated cumulative mortality percentage change per 1°C decrease in maximum temperature by age and gender groups, in Northern Ireland during winter[†] for ages ≥18 years, 1984–2007*

	Male and Female			All Ages	
	18-64 years	65-74 years	75+ years	Male	Female
	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)	% Change (95% CI)
All-cause Mortality [†]	2.7 (-0.7, 6.0)	4.5 (1.6, 7.3)	5.1 (3.3, 6.9)	4.8 (2.8, 6.8)	4.3 (2.4, 6.2)
CVD [†]	4.3 (-1.7, 10.3)	4.7 (-0.1, 9.6)	3.5 (0.1, 6.8)	5.1 (1.8, 8.5)	2.6 (-0.9, 6.1)
IHD [†]	3.6 (-3.0, 10.3)	5.2 (-0.3, 10.6)	3.1 (-0.9, 7.2)	4.4 (0.6, 8.2)	3.1 (-1.3, 7.4)
MI [†]	4.0 (-3.5, 11.6)	4.3 (-1.6, 10.3)	3.3 (-1.2, 7.8)	4.1 (0.02, 8.3)	3.2 (-1.3, 7.8)
Respiratory Disease [‡]	15.3 (0.5, 30.2)	12.8 (2.3, 23.2)	10.4 (4.9, 15.8)	9.2 (3.0, 15.4)	12.9 (7.2, 18.6)
COPD [†]	11.4 (-7.0, 29.7)	15.6 (2.6, 28.6)	7.8 (-2.0, 17.6)	10.4 (1.7, 19.2)	10.9 (0.7, 21.1)
Pneumonia [‡]	19.2 (-6.3, 44.7)	9.5 (-7.6, 26.6)	9.7 (2.4, 17.1)	7.4 (-1.1, 15.9)	11.9 (5.0, 18.8)
Stroke [†]	6.2 (-8.0, 20.3)	3.3 (-6.8, 13.5)	5.0 (-0.3, 10.4)	6.8 (0.2, 13.4)	3.6 (-1.5, 8.7)

Abbreviations: CI = confidence intervals, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, IHD = ischemic heart disease, MI = myocardial infarction. *Models included mortality data for ages ≥18 years, and were adjusted for Lag0 of maximum temperature, relative humidity and atmospheric pressure averaged over 3 days lag, and day of week. % Change = estimated mortality percentage change per 1°C decrease in weekly mean of maximum temperature. [†]Winter Months = December to February. [‡]Effect modification examined for cumulative change for lags of week 1 to 4; and (†) for cumulative change for lags of week 1 to 3.

The findings here are also consistent with a previous Irish study [22] which examined the relationship between cold weather and mortality in Dublin over a period of 17 years, using Poisson regression models. They reported mortality increases for all-cause (2.6%), CVD (2.5%), and respiratory disease (6.7%) in relation to 1°C decrease in mean daily temperature up to 40 days preceding death. Similar results were observed in Scotland for all-cause, CVD and respiratory mortality with cold temperatures during the month prior death [29,32]. Multi-city studies in Europe and the US reported similar increases for all-cause and cause-specific mortality from cold weather during winter and persistence of these associations, with similar lag periods as presented here [1,2].

Only a small number of studies have looked at the association between cold temperature and mortality from COPD, pneumonia and stroke. An earlier study of 12 cold-climate US cities did not observe any increase in COPD mortality in relation to cold, but their reported increase for pneumonia mortality is comparable with those reported here [26]. Another US study reported elevated risk of dying of COPD associated with cold weather, in an elderly population [33]. Analitis et al. reported increases in stroke mortality associated with cold temperatures over 15 days before death [1], and other studies in Russia and Asia reported similar findings [31,34,35].

Weaker associations for CVD and stroke mortality were observed in relation to cold temperatures in the second week before death, with increases in mortality recovering in the week following. This phenomenon has been described previously as harvesting, which is likely due to the depletion in numbers by premature mortality of those most susceptible to cold weather [22,36,37]. The extended cold weather-mortality associations observed in our study suggest that there is potentially a

cumulative health effect of cold weather and gradual weakening and displacement by death [22,36,37], also evidenced by a small number of epidemiologic studies that have considered long lag structures [1-3,22,32,38].

Some suggestive differences in the cold weather-mortality associations by age and gender were observed in both jurisdictions. Corroborating our study findings, Analitis et al. and Goodman et al. reported increasing cold temperature-mortality associations with age [1,22]; age or gender differences of this relationship have not been confirmed by other studies [7,39].

This study observed some small differences in the associations of cold weather and mortality between the two Irish jurisdictions. The fact that the island of Ireland is relatively small, with similar weather, population characteristics and demographics, then any observed differences in the population response to the exposure to cold weather is most likely due to different public policies, socioeconomic construct, and health care systems in the two jurisdictions. Currently, there are winter fuel allowances and cold weather payments which target vulnerable population groups in both jurisdictions; however, these schemes differ substantially from each other [40-44]. The effectiveness of these cold weather and winter fuel payments in NI at reducing winter mortality have not been examined; in the ROI it has been suggested that the fuel allowance was not sufficient in meeting home-heating costs, and this was likely due to the contribution of poor thermal efficiency and low household income [11]. Rising fuel prices and demographic changes, combined with the economic recession have contributed to high levels of fuel poverty in the ROI, especially in relation to vulnerable households such as older people, those living alone and lone parent households [10,12,45,46]. The jurisdictional differences in housing stock, insulation and

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heating, also related to socioeconomic deprivation, influence the extent of fuel poverty [11,46,47]. In addition, differences in the identification of the 'fuel poor' and 'those most in need' can also impact upon the effectiveness and differences of the schemes in the two jurisdictions [46,48,49].

A very strong relationship has been observed between the incidence of fuel poverty, social class, geographic and demographic patterns of those most susceptible on the island of Ireland [11,47]. In both jurisdictions, the number of older people vulnerable to ill-health from cold homes will increase as part of significantly aging population [10]. Currently, there is a concentration of fuel poverty amongst rural older persons households in NI; fuel poverty is highest in most urbanized and very rural areas in the ROI [10,11]. A greater proportion of older people in NI live alone and in social housing when compared to the ROI [10]. Jurisdictional differences in general population health status, provision of and access to health care, and distribution of health and social inequalities, potentially contribute in concurrence with these policies, and may explain some of the observed differences in the cold weather-mortality associations.

It is important to recognize that climate change induced weather patterns will affect the long term cold weather-mortality relationship. Research suggests that increasing global mean temperatures will do little to reduce morbidity and mortality in winter [4,6,50,51], likely due to increases in temperature variability and weather extremes. These weather patterns have also been observed on the island of Ireland in the past few decades [8,9]; on this basis only, it may be possible that winter mortality will change over time. However, whether this change will be an increase or decrease is much more complex and multifaceted, and will depend on how rapidly the climate changes, how quickly the population adapt, and on infrastructural and policy interventions, and remains a challenge particularly in view of the aging population on the Island. To understand long term patterns of the cold weather-mortality association, additional analyses were carried out to examine this relationship for different time periods in each jurisdiction. Findings suggested a slight diminishing of the cold weather-mortality relationship in both jurisdictions over time. These findings however, need to be interpreted with caution, considering the complexity of the relationship of mortality and cold winters and the influence of the societal factors discussed earlier.

Conclusions

This study found strong associations between cold temperatures and mortality with impacts of cold weather persisting up to several weeks, in both Irish jurisdictions. The findings show that increased mortality from cold weather on the island of Ireland is an important and

topical public health issue. As the island of Ireland currently has the highest levels of excess winter mortality in Europe, with an estimated 2,800 excess deaths during each winter [12], the key challenges are to develop and implement policies which tackle fuel poverty and reduce winter morbidity and mortality. The fact that some differences in cold weather-mortality patterns are observed between the two jurisdictions, albeit small, suggests that policies and their implementation, and other societal factors potentially play a role in determining population health patterns.

Abbreviations

*C: Degrees celsius; CI: Confidence intervals; COPD: Chronic obstructive pulmonary disease; CVD: Cardiovascular disease; ICD: International classification of diseases; IHD: Ischemic heart disease; MI: Myocardial infarction; NI: Northern Ireland; ROI: The Republic of Ireland; SD: Standard deviation.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Conceived, designed and coordinated the study: AZ, PG, SB, HM. Analysed the data: AZ, SB. Assisted with data acquisition: PG, HM. Interpretation of data, results and wrote the paper: AZ, PG, SB, HM. All authors read and approved the final version of this manuscript.

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