The Public Health Benefits of Smoking Ban Policies:

Epidemiologic Analyses of Mortality Effects and Differentials by Socioeconomic Status

A thesis submitted for the degree of

Doctor of Public Health

by

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September 2013

Table of Contents

Abstract........8

Acknowledgements........9

List of Abbreviations........10

Chapter 1: Introduction........11

1.1. The Harmful Effects of Secondhand Smoke Exposure........11

1.2. Smoking Ban Policies as Public Health Interventions........13

1.3. Debate Surrounding Smoking Ban Policies........14

1.4. Thesis Purpose and Aims........15

1.5. Overview of Thesis Design and Methodology........16

Chapter 2: Do the Cardiovascular and Respiratory Effects of Smoking Ban Policies Differ by Socioeconomic Status? Review and Narrative Synthesis of Epidemiologic Evidence........20

2.1. Abstract........20

2.2. Introduction........21

2.3. Methods........23

2.4. Results........26

2.5. Discussion........64

2.6. Conclusion........70

2.7. Update: Newly Published Studies........70

Chapter 3: Reductions in Cardiovascular, Cerebrovascular, and Respiratory Mortality following the National Irish Smoking Ban: Interrupted Time-Series Analysis........80

3.1. Abstract........80

3.2. Introduction........81

3.3. Methods........82

3.4. Results........91

3.5. Discussion........110

3.6. Conclusion........115

Chapter 4: Socioeconomic Differentials in the Immediate Mortality Effects of the National Irish Smoking Ban: Principal Component and Interrupted Time-Series Analyses........116

4.1. Abstract........116

4.2. Introduction........117

4.3. Methods........119

4.4. Results........126

4.5. Discussion........138

4.6. Conclusion........148

Chapter 5: Discussion..149

5.1. Principal Findings of Thesis Research..149

5.2. Limitations and Strengths..153

5.3. Implications for Public Health Research, Policy, and Practice..159

Chapter 6: Conclusion..162

References..165

Appendix 1: Brunel University Ethics Approval Letter..185

Appendix 2: Authored *PLoS One* Publication..186

List of Figures

Figure 1.1: The Health Consequences Causally Linked to Smoking and Exposure to Secondhand Smoke....12

Figure 1.2: Number of Research Studies Conducting Narrative Synthesis as Indexed in PubMed, 1980-2012....17

Figure 1.3: Number of Research Studies Conducting Time Series Analysis as Indexed in PubMed, 1980-2012....18

Figure 1.4: Number of Research Studies Conducting Principal Component Analysis as Indexed in PubMed, 1980-2012....19

Figure 2.1: Flowchart of Study Selection Process....25

Figure 2.2: Pre- and Post-Ban Assessment Periods for Primary Studies of Smoking Ban Health Effects....48

Figure 3.1: Interpretation of Interrupted Time-Series Model Results....89

Figure 3.2: Crude Mortality Rates in the Irish Population, Aged ≥35 Years, 2000-2007....92

Figure 3.3: Mortality Distribution by Sex in the Irish Population, Aged ≥35 Years, 2000-2007....92

Figure 3.4: Mortality Distribution by Age Category in the Irish Population, Aged ≥35 Years, 2000-2007....93

Figure 3.5: Observed Monthly Mortality in the Republic of Ireland, 2000-2007....94

Figure 3.6: Influenza-Like Illness (ILI) Rate per 100,000 Population by Week during the 2000-2001, 2005-2006, 2006-2007, and 2007-2008 Influenza Seasons, Republic of Ireland....95

Figure 3.7: Monthly Mortality Comparison between Acute Myocardial Infarction and Diabetes in the Republic of Ireland, 2000-2007....103

Figure 3.8: Seasonal Adjustments with Annual and Semi-Annual Sine/Cosine Terms versus Calendar Months, Predicted Weekly Stroke Deaths in the Irish Population, Aged ≥35 Years, 2000-2007....105

Figure 3.9: Monthly Smoking Prevalence in Ages ≥15 Years, Republic of Ireland, July 2002-December 2007....108

Figure 3.10: Monthly Smoking Prevalence in Males, Ages ≥15 Years, Republic of Ireland, July 2002-December 2007....108

Figure 3.11: Monthly Smoking Prevalence in Females, Ages ≥15 Years, Republic of Ireland, July 2002-December 2007....109

Figure 3.12: Mean Number of Cigarettes Smoked per Day in Ages ≥15 Years, Republic of Ireland, July 2002-December 2007....109

Figure 4.1: Immediate Post-Smoking Ban Mortality Effects by Structural Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010..............................131

Figure 4.2: Immediate Post-Smoking Ban Mortality Effects by Material Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010..............................132

Figure 4.3: Immediate Post-Smoking Ban Mortality Effects by Composite Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010..............................134

Figure 4.4: Immediate Post-Smoking Ban Mortality Effects by Separate Factor Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010..............................135

Figure 4.5: Immediate Post-Smoking Ban Mortality Effects by Previously Published Deprivation Index Scores, Ages ≥35 years, Republic of Ireland, 2000-2010...........................137

Figure 4.6: Percent Compliance with the National Irish Workplace Smoking Ban, 2004-2010..146

List of Tables

Table 2.1: Chronological Summary of Primary Epidemiological Studies Assessing the Cardiovascular and Respiratory Effects of Smoking Ban Policies..27

Table 2.2: Critical Appraisal of Empirical Studies Assessing the Health Effects of Smoking Ban Policies..41

Table 2.3: Groupings of Primary Study Characteristics for Narrative Synthesis......................50

Table 2.4: Primary Epidemiological Studies Assessing the Health Effects of Smoking Ban Policies by Socioeconomic Status (SES)...61

Table 2.5: Newly Published Studies: Update of Chronological Summary of Primary Epidemiological Studies Assessing the Cardiovascular and Respiratory Effects of Smoking Ban Policies..72

Table 2.6: Newly Published Studies: Update of Primary Epidemiological Studies Assessing the Health Effects of Smoking Ban Policies by Socioeconomic Status (SES)..................................78

Table 3.1: Goodness of Fit Statistics Comparing Linear versus Non-Linear Time Trends in Mortality, Ages ≥35 years, Republic of Ireland, 2000-2007..84

Table 3.2: Durbin-Watson Statistics Representing First-Order Autocorrelation of the Weekly Mortality Time-Series in Ages ≥35 years, Republic of Ireland, 2000-2007..............................84

Table 3.3: Age and Gender-Standardised All-Cause (Non-Trauma) and Cause-Specific Mortality Rates per 10,000 Population for Ages ≥35 years in the Republic of Ireland, 2000-2007..85

Table 3.4: Multivariate Analysis of Annual Pre-Ban Changes in Overall and Gender-Specific Mortality Rates, Ages ≥35 years, Republic of Ireland, 2000-2007...96

Table 3.5: Multivariate Analysis of Annual Pre-Ban Changes in Mortality Rates by Age Category, Republic of Ireland, 2000-2007..96

Table 3.6: Multivariate Analysis of Overall and Gender-Specific Post-Ban Effects on Mortality Rates, Ages ≥35 years, Republic of Ireland, 2000-2007..98

Table 3.7: Multivariate Analysis of Post-Ban Effects on Mortality Rates by Age Category, Republic of Ireland, 2000-2007..98

Table 3.8: Short-Term Mortality Effects of the National Smoking Ban in the Republic of Ireland, Implemented 29 March 2004, Ages ≥35 Years, 2000-2007.......................................99

Table 3.9: Longer-Term Effects of the National Smoking Ban in the Republic of Ireland, Implemented 29 March 2004, Ages ≥35 Years, 2000-2007..100

Table 3.10: Multivariate Analysis of Effects on Mortality Rates in Ages ≥35 years with the Use of False Ban Dates, Republic of Ireland, 2000-2007...101

Table 3.11: Multivariate Analysis of Overall Changes in Mortality Rates, Ages ≥35 years, Republic of Ireland, Including Winter 1999-2000 (from week 48 of 1999 to week 51 of 2007)..104

Table 3.12: Multivariate Analysis of Overall Changes in Mortality Rates, Ages ≥35 years, Republic of Ireland, Excluding Winter 1999-2000 (from week 14 of 2000 to week 51 of 2007)..104

Table 3.13: Multivariate Analysis of Overall Changes in Mortality Rates with Adjustment for Season Using Annual and Semi-Annual Sine and Cosine Terms, Ages ≥35 years Republic of Ireland, 2000-2007...106

Table 4.1: Pre- and Post-Smoking Ban Effects in Weekly Mortality Rates, Ages ≥35 years, Republic of Ireland, 2000-2010...123

Table 4.2: Descriptive Statistics of Area-Level Socioeconomic Indicators, Republic of Ireland, 2000-2010...128

Table 4.3: Spearman Correlation Coefficient Matrix for Area-Level Socioeconomic Indicators, Republic of Ireland, 2000-2010...128

Table 4.4: Principal Component Rotated Matrix for Composite Socioeconomic Indices, Republic of Ireland, 2000-2010...129

Table 4.5: Pre- and Post-Smoking Ban Effects in Monthly Mortality Rates, Ages ≥35 years, Republic of Ireland, 2000-2010...129

ABSTRACT

Background: The implementation of comprehensive smoking ban policies results in reduced population exposure to secondhand smoke, yielding health benefits such as improved respiratory function and decreased risk of cardiovascular events. However, smoking ban effects on respiratory and cerebrovascular mortality and effect differences by socioeconomic status (SES) are unknown.

Methods: A literature review was conducted to understand the health benefits of smoking ban policies and to identify areas of research that needed to be addressed. Subsequently, an epidemiologic study employing an interrupted time-series approach was conducted with a national mortality dataset from the Republic of Ireland to determine effects following the implementation of the national workplace smoking ban. Irish census data were used to calculate frequencies of deprivation at the level of the local authority and principal component analysis was conducted to generate a composite SES index. To determine whether the smoking ban policy impacted inequalities, Poisson regression with interrupted time-series analysis was conducted to examine mortality rates, stratified by tertiles of discrete SES indicators and the composite index.

Results: The review identified strong evidence for post-ban reductions in cardiovascular morbidity and mortality, and suggestive evidence of reductions in respiratory morbidity following smoking ban implementation. Few studies assessed ban effects by SES and findings were inconsistent; hence, insufficient evidence was available to determine smoking ban policy impacts on health inequalities. Epidemiologic analyses demonstrated that the national Irish smoking ban was associated with immediate reductions in early mortality for cardiovascular, cerebrovascular, and respiratory causes. Further analyses by discrete socioeconomic indicators and a composite index indicated that the national Irish smoking ban was associated with decreased inequalities in smoking-related mortality.

Conclusions: Smoking ban policies are effective public health interventions for the prevention of cardiovascular, cerebrovascular, and respiratory mortality. Furthermore, findings indicate that smoking ban policies have the potential to reduce inequalities in mortality.

Acknowledgments

My most sincere appreciation goes to Dr. Ariana Zeka who provided constant guidance, assistance, and friendship through the many challenges arising during thesis research. Thanks also go to Prof. Pat Goodman, Prof. Luke Clancy, and Dr. Zubair Kabir for providing data, access to research articles, and collaborative suggestions relating to the thesis projects. Most importantly, I thank my husband, Jeffrey W. Smith, who in simultaneously working towards his Ph.D, offered the understanding and support that could only be provided by one also in the midst of the struggles of thesis research. Finally, I thank my family, both parents and siblings, for loving me unconditionally and giving me the courage to pursue my aspirations.

List of Abbreviations

95% CI	95% Confidence Interval
ACE	Acute Coronary Events
ACS	Acute Coronary Syndrome
AIC	Akaike Information Criterion
AMI	Acute Myocardial Infarction
BIC	Bayesian Information Criterion
CDC	Centers for Disease Control and Prevention
CHD	Coronary Heart Disease
COPD	Chronic Obstructive Pulmonary Disease
CSO	Central Statistics Office Ireland
CVD	Cardiovascular Disease
FCTC	Framework Convention on Tobacco Control
HPSC	Health Protection Surveillance Centre Ireland
ICD	International Classification of Diseases
IHD	Ischemic Heart Disease
ILI	Influenza-like Illness
OR	Odds Ratio
OTC	Office of Tobacco Control Ireland
PCA	Principal Component Analysis
RR	Rate Ratio
SES	Socioeconomic Status
SHS	Secondhand Smoke
WHO	World Health Organization

CHAPTER 1: Introduction

This chapter outlines the harmful effects of passive exposure to secondhand smoke (SHS), discusses smoking ban policies as public health interventions, highlights the known post smoking-ban environmental and public health benefits, and briefly discusses the contentious debate still surrounding the adoption and implementation of smoking ban policies. The aims and objectives of the thesis are then described, with a brief explication of the rationale for thesis design and methodology.

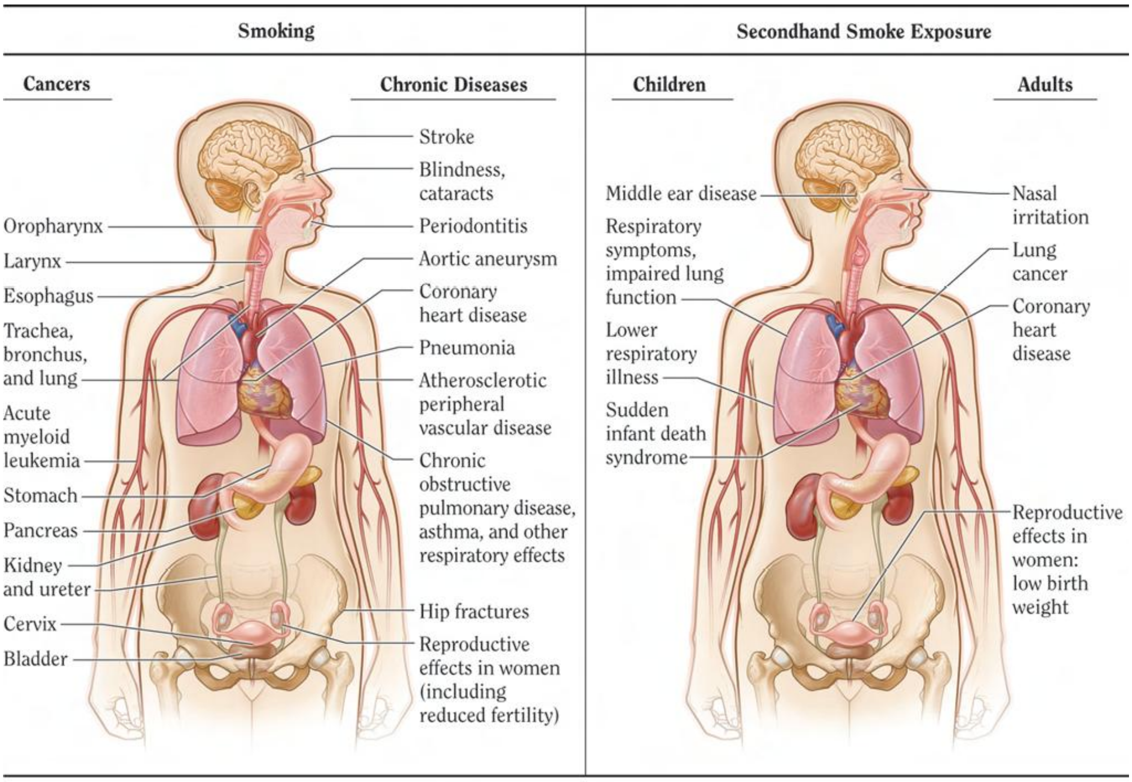
1.1. The Harmful Effects of Secondhand Smoke Exposure

Tobacco use is one of the major preventable threats to public health and is responsible for nearly six million annual deaths worldwide, including more than 600,000 deaths in non-smokers due to SHS exposure (WHO, 2011). Tobacco smoke is composed of an estimated 5,300 chemicals, and although less than half of these components have been assessed for potential toxicity, many have already been proven to be hazardous to human health (Talhout et al., 2011). SHS is a mixture of sidestream smoke, the smoke that exudes from the burning end of a cigarette, and mainstream smoke, the smoke that is directly exhaled from the person smoking the cigarette (Rubenstein et al., 2004). Although it is well known that active smoking is associate with increased risk for cardiovascular (Ockene & Miller, 1997), cerebrovascular (Ockene & Miller, 1997; Shinton & Beevers, 1989), and respiratory diseases (CDC, 2004), it is lesser known, particularly to the public, that passive exposure to tobacco smoke is also associated with these and other negative health outcomes (Figure 1.1) ("A Report of the Surgeon General," 2010).

Exposure to SHS can cause blood platelet aggregation, endothelial damage, and other physiological changes which can induce a cerebrovascular or cardiovascular event (Glantz & Parmley, 1995; Pechacek & Babb, 2004; Pope et al., 2009). Even short-term exposure to SHS in non-smokers can result in similar negative health effects as those experienced by active smokers (Barnoya & Glantz, 2005). Self-reported data have been used to estimate the cerebrovascular effects of exposure to SHS in non-smokers and long-term ex-smokers, demonstrating increased odds of acute stroke

(Odds Ratio (OR)=1.82; 95% CI: 1.34-2.49) for persons who lived in the same household or worked in the same, enclosed room with an active smoker for more than one year (Bonita et al., 1999). Biological specimens of blood or saliva may be obtained to gain a more precise estimate of recent SHS exposure in non-smokers by measuring the level of cotinine, a metabolite of nicotine, present in the specimens (CDC, 2012). The use of this biomarker in non-smokers has demonstrated that higher concentrations of serum cotinine are associated with a 50-60% excess risk in coronary heart disease (CHD) (Whincup et al., 2004). As secondhand smoke is an irritant, it has been shown to be associated with dose-dependent increased odds of wheezing (OR=1.94; 95% CI: 1.39-2.70), chronic bronchitis (OR=1.65; 95% CI: 1.28-2.16), and physician-diagnosed asthma (OR=1.39; 95% CI: 1.04-1.8) (Leuenberger et al., 1994). Thus, interventions to reduce exposure to SHS have the potential to result in large public health benefits.

Figure 1.1: The Health Consequences Causally Linked to Smoking and Exposure to Secondhand Smoke. Reproduced from: ("A Report of the Surgeon General," 2010)



1.2. Smoking Ban Policies as Public Health Interventions

The main purpose of smoking ban policy implementation is to reduce SHS exposure in the population, although a concurring benefit may also be reductions in active smoking. Smoking ban policies can differ in levels of coverage and the extent to which legislative action may be taken against violators. A comprehensive smoking ban is one in which smoking is prohibited in all public workplaces, including bars, pubs, and restaurants. A partial smoking ban is one which allows exceptions for smoking in certain venues. For example, separate smoking areas may be allowed in a certain percentage of a bar, pub, or restaurant providing that a ventilation system is installed. However, exposure studies have demonstrated that ventilation systems do not provide adequate protection from potentially harmful respirable particles for either workers or patrons (Goodman et al., 2007; Repace, 2004; Repace et al., 2006). Furthermore, a study specifically comparing the health effects of a partial and a comprehensive smoking ban implemented in two different locations in Argentina, demonstrated that health benefits were only seen in the area that was covered by the comprehensive smoking ban (Ferrante et al., 2012). Since no level of exposure to secondhand smoke is safe (CDC, 2006), partial smoking bans are less effective in protecting health when compared to comprehensive smoking bans (Erazo et al., 2010; Fernandez et al., 2009; Martinez-Sanchez et al., 2009; Naiman et al., 2011; Tan & Glantz, 2012).

Comprehensive smoking ban policies have indeed been shown to be effective public health interventions for reducing both exposure to SHS and other indoor air pollutants (Connolly et al., 2009; Fong et al., 2006; Goodman et al., 2007; Mulcahy et al., 2005; Valente et al., 2007). Also, as will be extensively discussed in Chapter 2, there is a substantial evidence base that smoking ban policies result in decreases in cardiovascular and respiratory morbidity, with fewer studies also indicating decreases in cardiovascular mortality. Although these studies have shown that smoking ban policies yield population-wide health improvements, evidence of impacts on inequalities is extremely limited.

1.3. Debate Surrounding Smoking Ban Policies

The Republic of Ireland was the first country in the world to enact a national, comprehensive, workplace smoking ban policy; however, other types of smoking ban policies have been in existence since the 1990s. For instance, the California statewide smoking ban was partially implemented in 1995, and was later extended to include restaurants and bars in 1998 ("Americans for Nonsmokers' Rights," 2013). This begs the questions of why, with so much time for public health researchers to gather evidence on the effects of smoking ban policies, there is still such contentious debate surrounding their implementation. The reason is that the tobacco industry, in order to protect profits, has employed their considerable financial resources towards creating controversy surrounding the scientific evidence as well as towards political lobbying against the legislative adoption of such policies (Apollonio & Bero, 2007; Hong & Bero, 2002; Landman & Glantz, 2009; Michaels, 2006; Muggli et al., 2001; Muggli et al., 2003; Ong & Glantz, 2001; Samet & Burke, 2001).

For example, the tobacco industry has made many false claims to the public, using discourse in the media implying that smoking ban policies result in severe economic losses to the hospitality and gaming industries due to the decreased patronage of smokers and associated job losses (Dearlove et al., 2002; Mandel & Glantz, 2004). However, studies across several countries have demonstrated that, following smoking ban implementation, the related hospitality (Dearlove et al., 2002; Hyland & Cummings, 1999; Hyland et al., 2000) and gaming industries (Mandel et al., 2005) did not economically suffer either from decreased patronage or job losses and, in some cases, even benefitted from increased profitability (Hyland & Cummings, 1999). In fact, it has been shown that the costly installation of ventilation systems to maintain smoking rooms in bars, restaurants, and casinos is much more expensive for venue owners in the hospitality industry than simply prohibiting smoking inside the entire premises (Dearlove et al., 2002).

Additionally, the tobacco industry has tried to frame the adoption of smoking ban policies as an infringement of personal rights, claiming that these policies go beyond the purview of the government and extend to the extreme of enforcing a population-wide moral code. In response to this, the World Health Organization (WHO) has issued a statement that the right to breathe clean air takes precedence over the right of someone who would put the health of others in danger (WHO, 2007c). Closely related to this concept is the potential risk that the restriction of smoking in public places would result in the displacement of smoking into the home, resulting in increased SHS exposure among non-smokers, especially children. However, several studies of post-ban SHS exposure in children have consistently refuted this claim and have shown that there is no indication of smoking displacement into the home (Akhtar et al., 2007; Moore et al., 2012; Sims et al., 2012a).

In May 2003, the World Health Assembly adopted the Framework Convention on Tobacco Control (FCTC), an international treaty which established guidelines relating to tobacco advertising, tax and price measures, tobacco packaging, and smoke-free legislation (WHO, 2005). Although 168 countries ratified the FCTC within the first year, as of 2010, only 11% of the global population was covered by a smoke-free policy (WHO, 2011). A recent assessment of the extent to which tobacco control research has influenced policy found that research on smoking bans has already substantially impacted policymaking in the past and will likely be strongly influential in the future policy debates for states and countries not currently protected (Warner & Tam, 2012). Strong evidence of the public health benefits of smoking ban policies is needed to support the political will for broader implementation across populations.

1.4. Thesis Purpose and Aims

The purpose and primary aims of this thesis are as follows:

1. To review the published literature to date regarding the cardiovascular and respiratory health effects of smoking ban policies, to assess effect differences by socioeconomic status (SES), and to identify unexplored areas of research on the public health effects of smoking ban policies.
2. To examine both the immediate and gradual effects of the national Irish smoking ban by analysing all-cause and cause-specific, non-trauma mortality in the Irish population, accounting for potential confounding factors.

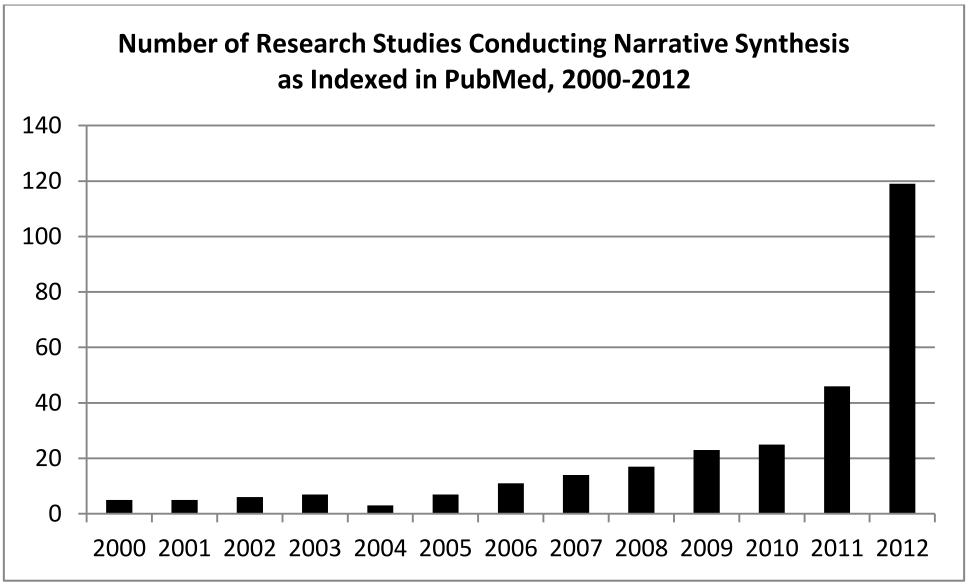
3. To determine the impacts of the national Irish smoking ban on inequalities in mortality by examining area-level SES differences in immediate post-smoking ban effects.

1.5. Overview of Thesis Design and Methodology

The Doctor of Public Health (DrPH) Programme at Brunel University was intended to be based upon three research internships in research, policy, and practice. However, as the programme was relatively new and had undergone administrative changes, it was deemed best by the programme director and other faculty members affiliated with the programme that current DrPH students undertake three interrelated thesis research projects within the purview of policy and practice. Therefore, in accordance with the DrPH guidelines, the body of this thesis is composed of three research reports arising from these projects and is intended to be presented in a form allowing for straightforward abbreviation leading to submission for publication in a relevant journal.

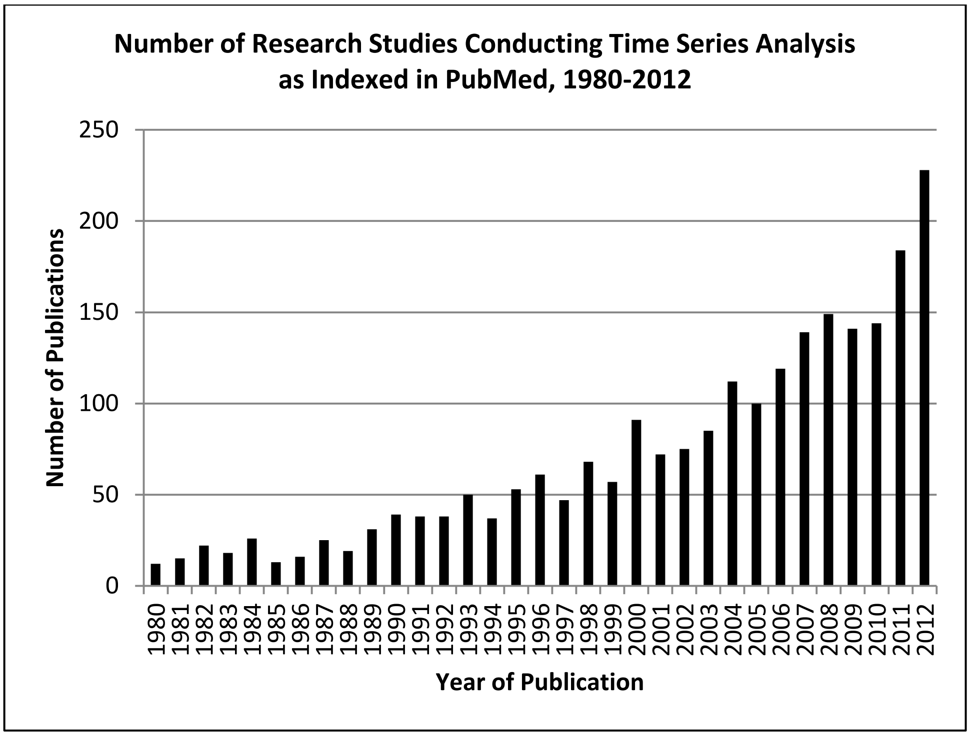
Chapter 2 describes the first research project, a review conducted to identify the breadth of available evidence on the cardiovascular and respiratory health effects of smoking ban policies and to determine whether documented post-ban effects differed by SES. The review was also intended to guide further thesis projects by providing an overview of the analytic methods employed for assessing smoking ban policy interventions, understanding the confounding and contextual factors that may influence post-ban health effects, and identifying areas wherein additional research was most critically needed; therefore, a narrative synthesis was determined to be the most appropriate method for compiling existing evidence. Although narrative synthesis is a relatively new research method, it is being increasingly used due to its flexibility and applicability when meta-analytic techniques are too restrictive or otherwise inappropriate. This was confirmed by a PubMed database search of English language articles which showed that the frequency of reporting that a 'narrative synthesis' was conducted, in either the title or abstract, has been steadily rising since 2005, with its use in the year 2012 more than doubling that reported in 2011 (Figure 1.2).

Figure 1.2: Number of Research Studies Conducting Narrative Synthesis as Indexed in PubMed, 2000-2012



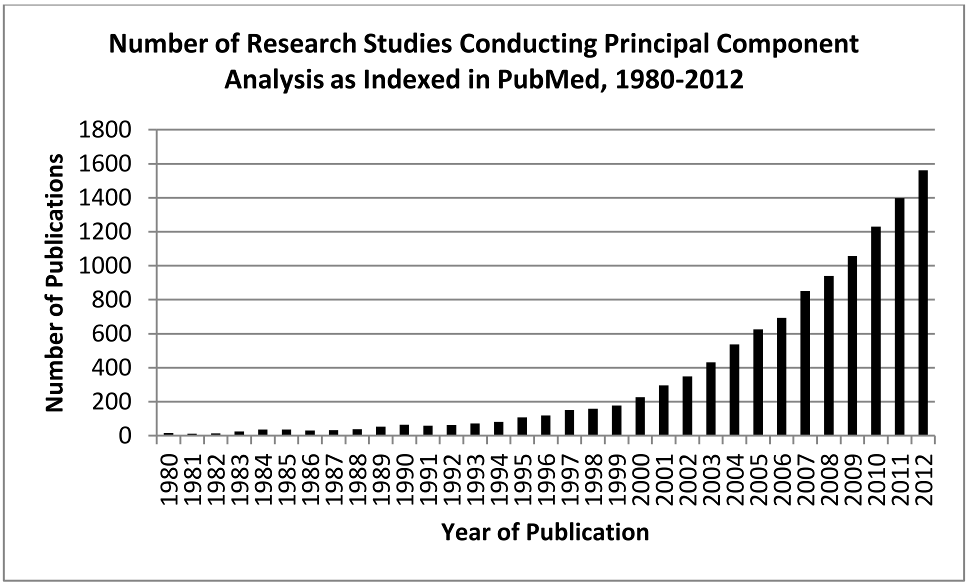
Chapter 3 describes the second thesis project, an epidemiologic analysis conducted to determine the all-cause and cause-specific, non-trauma mortality effects following the implementation of the national Irish workplace smoking ban. Interrupted time-series analysis has been recommended as the most applicable method for analysing population-wide interventions, chiefly because it allows adjustment for autocorrelation (Gottman, 1981) and consideration for underlying trends in the time series (Wagner et al., 2002). Indeed, the lack of control for underlying trends has been a major criticism employed by the tobacco industry in their attempts to undermine public health research in tobacco control. Because the response variable in this study was composed of count data, specifically the number of age and sex-adjusted mortality events per week, interrupted time-series Poisson regression with a log link function was conducted using the SAS GLIMMIX procedure to adjust for the detected serial autocorrelation. Although the generalised additive model (GAM) has been employed in similar analyses, it is, in contrast, based upon the underlying assumption that there is no serial autocorrelation of the time series (Yang et al., 2012); therefore, the use of a GAM was deemed inappropriate for this data. Due to the many benefits of time-series analysis, it has been progressively used in research as evident by the increasing number of English-language publications in the PubMed database citing ‘time series analysis’ in the title or the abstract (Figure 1.3).

Figure 1.3: Number of Research Studies Conducting Time Series Analysis as Indexed in PubMed, 1980-2012. Updated from: Szatkowski (2011)



Chapter 4 describes the third thesis project, an epidemiologic analysis of Irish mortality events matched to area-level census data to determine whether the immediate effects of the smoking ban differed by SES. Mortality effects were assessed both by discrete SES indicators and a composite index. Principal component analysis (PCA) was conducted to generate the composite index because it is the applicable variable reduction technique when the variables are correlated, condensing the number of observed variables into principal components (Suhr, 2005). Because these principal components account for the maximum amount of variance of the observed variables (Kline, 1994), PCA has been increasingly used in research as evidenced by the number of English-language publications citing ‘principal component analysis’ in the title or the abstract in the PubMed database (Figure 1.4).

Figure 1.4: Number of Research Studies Conducting Principal Component Analysis as Indexed in PubMed, 1980-2012



Chapter 5 provides an overall discussion of the projects, linking the findings together and elucidating the implications for public health research, policy and practice. Finally, Chapter 6 provides a brief summation of the overarching conclusions of the thesis.

CHAPTER 2: Do the Cardiovascular and Respiratory Effects of Smoking Ban Policies Differ by Socioeconomic Status? A Review and Narrative Synthesis

2.1. ABSTRACT

Objectives: To summarise the cardiovascular and respiratory health effects of smoking ban policies, to assess effect differences by socioeconomic status (SES), and to identify areas where future research is needed.

Methods: Systematic searches of PubMed and Web of Science, restricted to publications in English and limited by years 1990-2011, were conducted to identify relevant empirical studies with a smoking ban intervention and an outcome of cardiovascular or respiratory mortality or hospital-diagnosed morbidity. Additional studies published from January 2012 to January 2013 were identified through weekly electronic notification from both databases. Each study (n=37) was critically appraised and information was abstracted on intervention, population, assessment period, analytical methods, health effects, and assessment of effects by SES. Studies were thematically grouped for narrative synthesis.

Results: Strong evidence exists for post-ban reductions in cardiovascular morbidity and mortality, with the most cause-specific evidence available for acute myocardial infarction. Suggestive evidence indicates reductions in respiratory morbidity following smoking ban implementation, particularly for asthma. No evidence was available regarding smoking ban policy effects on respiratory mortality. Only three studies assessed post-ban effects by SES. Hence, insufficient evidence was available to determine smoking ban policy impacts on health inequalities.

Conclusions: Smoking ban policies are effective public health measures for reducing cardiovascular morbidity and mortality, but more cause-specific research is needed for outcomes such as stroke, particularly in relation to mortality. Further research is needed to confirm post-ban reductions in respiratory morbidity and to identify smoking ban policy effects on respiratory mortality. To achieve the public health aim of reducing inequalities in health, there is a critical need for future smoking ban research studies to examine health effects by SES.

2.2. INTRODUCTION

The link between socioeconomic status (SES) and health has consistently been demonstrated in epidemiologic research, with groups of lower SES experiencing worse outcomes (Davey Smith et al., 2001; Link & Phelan, 1995; Lynch & Kaplan, 2000; Shaw et al., 2006). Both active (WHO, 2009) and passive (WHO, 2011) smoking can result in morbidity and premature mortality. Since low SES groups have higher rates of smoking (Evandrou & Falkingham, 2002; Graham, 2009; Jarvis & Wardle, 2006; Paulik et al., 2011), the implementation of smoking ban policies has the potential to directly influence inequalities in smoking-related and secondhand smoke exposure-related health outcomes.

SES indicators such as education, occupation, and income represent access to resources that may affect exposures to risk factors or influence the ability to manage the progression of disease (Link & Phelan, 1995). These serve as markers for outcomes such as access to health care, availability and uptake of health education, and the financial autonomy that provides opportunities for health. Experiencing limited access to resources, along with limited social and personal esteem that comes with those resources, leads to poor health (Marmot & Bell, 2006) as there are fewer opportunities and less power and privilege to live a healthy life (Whitehead et al., 2009). With this in mind, assessments of population-level interventions should consider the multiplicity of factors that may influence health outcomes, including characteristics of population subgroups that affect response to public health interventions. Although smoking bans are population-level interventions that apply equally to all socioeconomic groups, the resulting effects on health inequalities are uncertain.

Previous research has indicated that the implementation of smoking ban policies yields many public health benefits, namely an overall 17-19% decrease in the incidence of acute myocardial infarction (AMI) (Glantz, 2008; Lightwood & Glantz, 2009; Meyers et al., 2009). Additionally, a meta-analysis of smoking ban effects on acute coronary events (ACE) yielded a pooled reduction estimate of 10% (Relative Risk=0.90; 95% CI: 0.86-0.94) post-implementation, with the greatest reductions demonstrated in studies with longer follow-up periods (Mackay et al., 2010b). A few of the primary studies included in the meta-analysis conducted subgroup analyses, but effects were only examined by age, sex, and premature versus non-premature events. None of the primary studies assessed cardiovascular effects by SES (Mackay et al., 2010b).

Previous reviews have also assessed the smoking ban outcomes of self-reported respiratory symptoms and measurements of pulmonary function. One review included 12 studies with outcomes of self-reported respiratory symptoms, ten of which demonstrated significant post-ban reductions, with varying effect sizes based upon symptom type (Callinan et al., 2010). Another review reported consistent post-ban decreases of 20-50% in respiratory and irritant symptoms in seven studies that utilised self-reported outcome measures (Goodman et al., 2009b). Of the three reviewed studies that measured lung function, improvements were seen for at least one measure in each of the studies, particularly for non-smokers (Goodman et al., 2009b).

At the time this research was undertaken, no review had assessed respiratory mortality or hospital-diagnosed morbidity. Since that time, a meta-analysis of the smoking ban policy effects on cardiovascular, cerebrovascular, and respiratory disease has been published, indicating significant reductions in each of the overarching diagnostic groups, including a 24% decrease in respiratory morbidity (Relative Risk=0.76; 95% CI: 0.68-0.85) (Tan & Glantz, 2012). The meta-analytic, pooled reduction estimates following smoking ban implementation provide strong epidemiologic evidence of the association between smoking ban policies and health effects, along with specific information of effects by age and sex. This review builds upon the findings of the Tan and Glantz (2012) meta-analysis through a narrative synthesis that considers additional contextual factors and explores the assessment of effects by SES.

Two prior systematic reviews sought to identify the most effective tobacco control interventions for reducing inequalities in secondhand smoke exposure, cigarette consumption, and smoking attitudes and behaviours (Main et al., 2008; Thomas et al., 2008). The first review demonstrated that although there was sufficient evidence to make determinations regarding interventions such as cigarette price increases and restrictions on sales to minors, there was insufficient information to assess differential effects by income, education, or ethnicity for smoking restrictions in workplaces and public places (Thomas et al., 2008). The second review assessed the equity effects of various tobacco control interventions by examining existing systematic reviews (Main et al., 2008). The findings indicated that due to insufficient evidence in the individual reviews, the potential for smoke-free legislation to decrease social inequalities in smoking was unable to be determined (Main et al., 2008).

Reducing inequalities in health is a public health priority. For that reason, there is a critical need to examine the health effects of smoking ban policies by SES. The objectives of this review are to summarise the current epidemiologic evidence of smoking ban policy effects on cardiovascular and respiratory morbidity and mortality and to assess effects by SES to understand impacts on health inequalities.

2.3 METHODS

Search Strategy and Study Selection

The inclusion criteria for the review were as follows:

1. The study must be a peer-reviewed publication of primary epidemiological research.
2. The intervention must be a smoking ban policy.
3. The outcome must be hospital-diagnosed (rather than self-reported) morbidity or mortality due to cardiovascular or respiratory causes.
4. The study must be written in the English language.

These inclusion criteria did not allow for an exhaustive review of all research studies of smoking ban health effects. However, a strict selection of studies was preferred in order to examine the published record of physician-documented health outcomes based upon established diagnostic criteria.

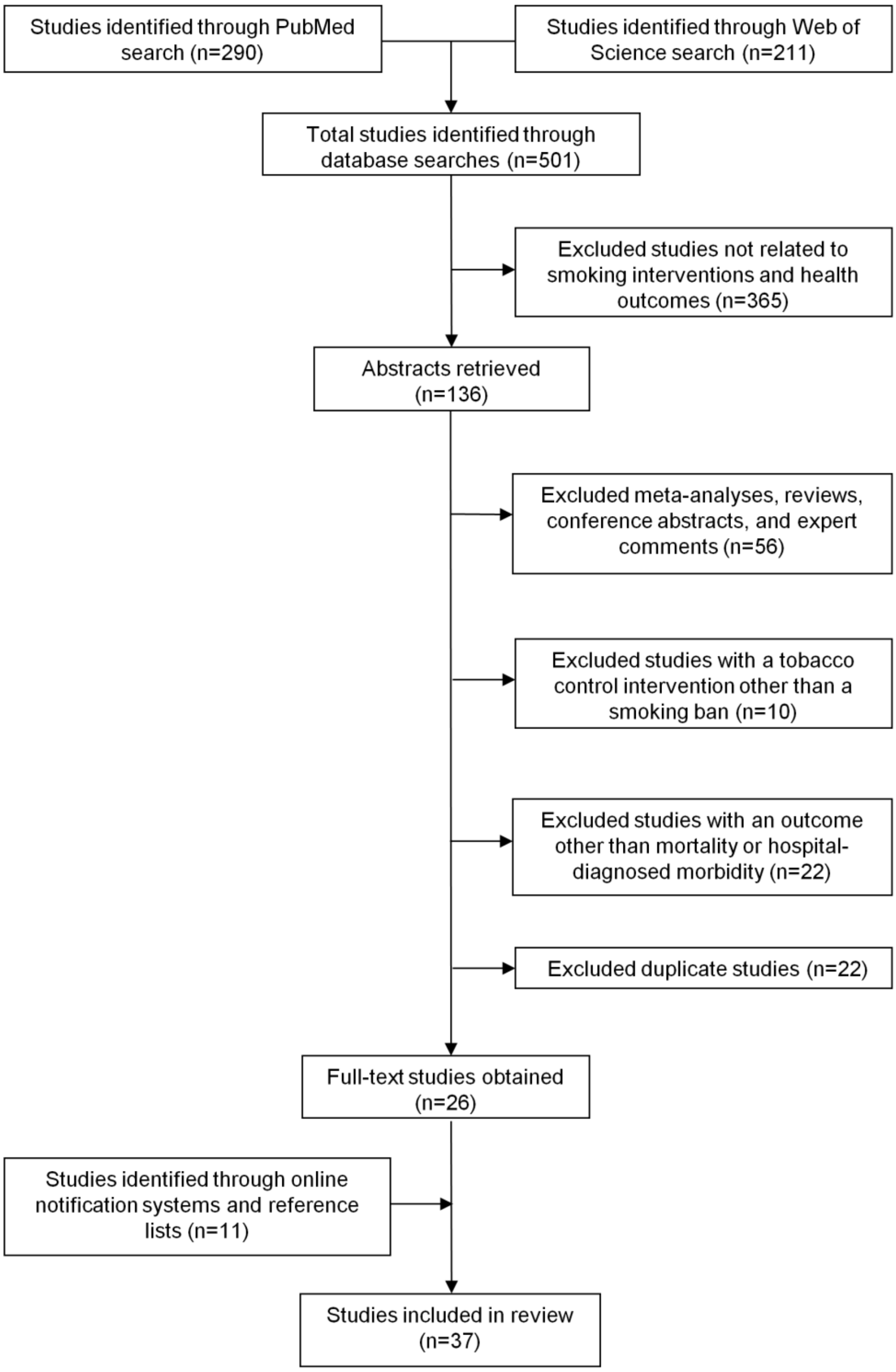
Systematic searches of PubMed and Web of Science were conducted using the following search terms: (anti smoking OR anti-smoking OR antismoking OR smoking OR smoke free OR smoke-free OR smokefree) AND (ban OR bans OR ordinance OR ordinances) AND (cardiovascular OR coronary OR myocardial infarction OR stroke OR angina OR respiratory OR asthma OR COPD OR pneumonia). The searches were restricted by a date range of 1990-2011 and to publications originally written in or translated into English. To maximise the research base for the review, searches were not restricted by study design.

The initial searches identified 501 publications. Upon review of the titles, 365 articles were excluded as irrelevant to smoking bans and health outcomes. Abstracts were retrieved and reviewed for the remaining 136 articles. Of these, 56 were excluded as they were meta-analyses, reviews, conference abstracts, or expert comments rather than peer-reviewed, primary epidemiological research studies. A further 32 studies were excluded either because the study intervention was a tobacco control measure other than a smoking ban (n=10) or because the outcome was a health measure other than mortality or hospital-diagnosed morbidity (n=22). Twenty-two studies were duplicates between the two databases. As a result, 26 full-text articles were obtained, all of which met the inclusion criteria for the review. During the review process, nine newly published studies were identified through the database electronic notification systems and two additional studies were identified through the reference lists of other articles; therefore, a total of 37 studies were included in the review (Figure 2.1).

Study Assessment and Data Extraction

A study quality assessment tool was developed based upon the *Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)* checklist and reported assessment methods from two previous reviews of tobacco control interventions (Aspinall, 2009; Thomas et al., 2008). A critical appraisal was conducted to assess the internal validity of each of the 37 primary epidemiological studies. Specifically, each study was evaluated based upon the clarity with which the intervention and outcome were defined, the level of adjustment for potential confounding factors, the validation of results through the use of a comparison population or control diagnosis, and the consideration for additional contextual factors, such as ban compliance, developments in clinical care, and population exposure to secondhand smoke. Funding sources and declared potential conflicts of interest were also noted. The studies were assessed chronologically to gain an understanding of the timeline in which the smoking ban policies were implemented and to explore the development of analytical methods over time.

Figure 2.1: Flowchart of Study Selection Process



Information was abstracted on the comprehensiveness of the smoking ban intervention, the study population and assessment period, the analytical methods, adjustment for potential confounders, and the overall and subgroup health effects. Corresponding authors were contacted as necessary for additional information, most often for enumeration of the study population, for clarification of study methods, or for obtaining a full-text copy of the article in the absence of a journal subscription. To aid in the narrative synthesis, the data extraction table was analysed for dominant characteristics as outlined in Rodgers et al. (2009). These groupings were then organised into a summary table. Further, the methodologies of each study were assessed for analyses of SES indicators such as education, occupation, income, or area deprivation. Two groups were used to classify the ways in which SES was utilised as a risk variable: 'Controlled as confounding factor' indicated that SES was analysed as an independent variable in regression analyses and 'Assessed for effect modification' indicated that SES was included as an interaction term in regression analyses or was stratified as a separate subgroup.

2.4. RESULTS

Overview of Studies

For each of the 37 studies, specific information regarding the smoking ban policy, study population and assessment period, analytical methods, adjustment for potential confounders, and observed health effects is summarised in Table 2.1. Within the summary table, several clusters of characteristics were identified and the resulting dominant groupings are shown in Table 2.2. The chronological assessment of the primary studies clearly demonstrated that the implementation of national, regional, county-wide, and city-wide smoking ban policies greatly increased from the year 2000. Methods for evaluating effects of these policies also developed over time, with interrupted time-series analyses largely replacing the before-and-after crude rate comparison analyses.

Table 2.1: Chronological Summary of Primary Epidemiological Studies Assessing the Cardiovascular and Respiratory Effects of Smoking Ban Policies

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Sargent et al. (2004) Helena, Montana, USA	City-wide comprehensive smoking ban including hospitality venues: 5 Jun. 2002 Suspended: 3 Dec. 2002	304 AMI hospital admissions in Helena (ban enforced) and surrounding areas (no ban enforced) Jun.-Nov. 1998-2003	Poisson analysis adjusting for season by study design	Helena: 40% decrease (95% CI: -79% to -1%) Surrounding areas: 45% increase (95% CI: -42% to 132%)	Not reported
Bartecchi et al. (2006) Pueblo, Colorado, USA	City-wide comprehensive smoking ban including hospitality venues: 1 Jul. 2003	2,794 AMI hospital admissions in Pueblo city limits (ban enforced), Pueblo County (no ban enforced) and El Paso County (no ban enforced 2002-2004	Poisson regression analysis adjusting for season	Pueblo City: Relative Risk=0.74 (95% CI: 0.64-0.86) Pueblo County: Relative Risk=0.87 (95% CI: 0.64-1.17) El Paso County: Relative Risk=0.99 (95% CI: 0.90-1.08)	Not reported
Barone-Adesi et al. (2006) Piedmont Region, Italy	National comprehensive smoking ban including hospitality venues: 10 Jan. 2005	17,153 AMI hospital admissions Feb.-Jun. 2001-2005	Mantel-Haenszel comparison analysis adjusting for season by study design and stratifying by age and sex	Rate Ratio (RR)=1.01 (95% CI: 0.97-1.06)	Age <60: RR=0.89 (95% CI: 0.81-0.98) Age ≥ 60: RR=1.05 (95% CI: 1.00-1.11)
Juster et al. (2007) New York State, USA	State-wide comprehensive smoking ban including hospitality venues: 24 Jul. 2003	462,396 AMI and 584,833 stroke hospital admissions in ages $\geq$35 years 1995-2004	Multiple linear regression with interrupted time series analysis adjusting for linear time trend, season, pre-existing smoking restrictions, county-level CV risk factors, and age	8% decrease (95% CI: not reported) Monthly AMI trend rate: 0.32 decrease (95% CI: -0.47 to -0.16) per 100,000 Monthly stroke trend rate: 0.06 increase (95% CI: -0.06 to 0.18) per 100,000	Not reported

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Khuder et al. (2007) Bowling Green, Ohio, USA	City-wide smoking ban in workplaces and public places, excluding bars, restaurants with bars and bowling alleys: Mar. 2002	CHD hospital admissions (# not reported) in ages ≥18 years in Bowling Green (ban enforced) and Kent (no ban enforced) Jan. 1999-Jun. 2005	Autoregressive integrated moving-average (ARIMA) time series analysis	Bowling Green after 1 year: 39% decrease (95% CI: -45% to -33%) Bowling Green after 3 years: 47% decrease (95% CI: -55% to -41%) Kent after 3 years: no change (p=0.945)	Not reported
Seo and Torabi (2007) Monroe County, Indiana, USA	County-wide workplace smoking ban excluding bars: 1 Aug. 2003 Amended to include bars: 1 Jan. 2005	37 AMI hospital admissions in Monroe County (ban enforced) and 48 AMI hospital admissions in Delaware County (no ban enforced) Aug. 2001-May 2005 (excluding Jun.-Jul. 2003)	Poisson analysis adjusting for season, co-morbidity, and past cardiac history by study design	Not reported	Monroe non-smokers: 71% decrease (95% CI: -125% to -16%) Monroe smokers: 13% decrease (95% CI: -107% to 82%) Delaware non-smokers: 11% decrease (95% CI: -75% to 52%) Delaware smokers: 25% decrease (95% CI: -177% to 67%)
Cesaroni et al. (2008) Rome, Italy	National comprehensive smoking ban including hospitality venues: 10 Jan. 2005	40,314 ACE hospital admissions and out-of-hospital deaths in ages 35-84 years 2000-2005	Poisson regression analysis adjusting for linear time trend, PM_{10} air pollution, temperature, influenza epidemics, holidays, total hospitalisation rates, age, sex, and SES	Not reported	Ages 35-64 years: RR=0.89 (95% CI: 0.85-0.93) Ages 65-74 years: RR=0.92 (95% CI: 0.88-0.97) Ages 75-84 years: RR=1.02 (95% CI: 0.98-1.07)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Lemstra et al. (2008) Saskatoon, Canada	City-wide comprehensive smoking ban including indoor public places and outdoor restaurant seating areas: 1 Jul. 2004	1,689 AMI hospital discharges Jul. 2000-Jun. 2005	Comparison analysis of age-standardised incidence rates from four years pre-ban to one year post-ban stratifying by age, sex, and prior AMI	RR=0.87 (95% CI: 0.84-0.90)	Not reported
Pell et al. (2008) Scotland	National comprehensive smoking ban including hospitality venues: 26 Mar. 2006	5,919 acute coronary syndrome (ACS) hospital admissions and 4,282 ACS out-of-hospital deaths in Scotland (ban enforced) and ACS hospital admissions (# not reported) in England (no ban enforced) Jun.-Mar. 2005-2007	Chi-square analysis and test for trend adjusting for season by study design and stratifying by serum cotinine-confirmed smoking status, age, and sex	Scotland: 17% decrease (95% CI: -18% to -16%) in ACS admissions Scotland: 6% decrease (95% CI: not reported) in ACS deaths England: 4% decrease (95% CI: not reported) in ACS admissions	ACS admissions in Scotland: Smokers: 14% decrease (95% CI: -16% to -12%) Former smokers: 19% decrease (95% CI: -21% to -17%) Never-smokers: 21% decrease (95% CI: -24% to -18%)
Rayens et al. (2008) Lexington-Fayette County, Kentucky, USA	County-wide, comprehensive smoking ban including hospitality venues: 27 Apr. 2004	14,839 asthma emergency department visits 2001-2006	Poisson regression and first-order autoregressive time-series analysis adjusting for time trend, season, age, and sex	Relative Risk=0.78 (95% CI: 0.71-0.86)	Age <20 years: Relative Risk=0.82 (95% CI: 0.71-0.96) Ages ≥20 years: Relative Risk=0.76 (95% CI: 0.69-0.84)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Vasselli et al. (2008) Piedmont, Friuli Venezia Giulia, Lazio, and Campania Regions, Italy	National comprehensive smoking ban including hospitality venues: 10 Jan. 2005	7,305 AMI hospital admissions in ages 40-64 years Jan.-Mar. 2001-2005	Comparison analysis of age and sex-standardised incidence rates from four years pre-ban to one year post-ban stratifying by age, sex, and region	RR=0.86 (95% CI: 0.83-0.92)	Males: RR=0.85 (95% CI: 0.81-0.91) Females: RR=0.98 (95% CI: 0.87-1.11) Ages 45-49 years: RR=0.77 (95% CI: 0.68-0.89) Ages 50-54 years: RR=0.74 (95% CI: 0.67-0.85) No effects detected in any other age groups
Barnett et al. (2009) Christchurch, New Zealand	National comprehensive smoking ban including hospitality venues: 10 Dec. 2004	3,079 AMI hospital admissions 2003-2006	Poisson regression analysis comparing age-specific rates from two years pre-ban to two years post-ban stratifying by age, sex, smoking status, and SES	RR=0.92 (95% CI: 0.86-0.99)	Males: RR=0.90 (95% CI: 0.82-0.99) Females: RR=0.94 (95% CI: 0.84-1.05) Ages 30-54 years: RR=1.15 (95% CI: 0.94-1.40) Ages 55-74 years: RR=0.86 (95% CI: 0.77-0.97) Ages ≥75 years: RR=0.89 (95% CI: 0.81-0.98)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
CDC (2009) Pueblo, Colorado, USA	City-wide comprehensive smoking ban including hospitality venues: 1 Jul. 2003	4,954 AMI hospital admissions and AMI deaths (# not reported) in Pueblo city limits (ban enforced), Pueblo County (no ban enforced) and El Paso County (no ban enforced) Jan. 2002-Jun. 2006	Chi-square comparison analysis of incidence rates between three periods: Pre-implementation: 0-18 months pre-ban Phase I: 0-18 months post-ban Phase II: 19-36 months post-ban	AMI admissions for Phase II v. Pre-implementation: Pueblo City: RR=0.59 (95% CI: 0.49-0.70) Pueblo County: RR=1.03 (95% CI: 0.68-1.39) El Paso County: RR=0.95 (95% CI: 0.87-1.03) AMI admissions and deaths for Phase II v. Pre-implementation: Pueblo City: RR=0.66 (95% CI: 0.55-0.77)	AMI admissions for Phase II v. Pre-implementation for Pueblo City: Males: RR=0.67 (95% CI: 0.52-0.82) Females: RR=0.48 (95% CI: 0.36-0.60)
Gasparrini et al. (2009) Tuscany Region, Italy	National comprehensive smoking ban including hospitality venues: 10 Jan. 2005	13,456 AMI hospital admissions and deaths in ages 30-64 years 2000-2005	Poisson regression with interrupted time-series analysis adjusting for season, linear time trend, non-linear time trend, age, and sex	Model with linear time trend: Relative Risk=0.95 (95% CI: 0.89-1.00) Model with non-linear time trend: Relative Risk=1.01 (95% CI: 0.93-1.10)	Model with linear time trend: Males: Relative Risk=0.95 (95% CI: 0.89-1.01) Females: Relative Risk=0.94 (95% CI: 0.82-1.09)
Villalbi et al. (2009) Barcelona, Spain	National workplace smoking ban excluding hospitality venues: 1 Jan. 2006	13,316 AMI hospital admissions in ages ≥25 years 2004-2006	Comparison analysis of age and sex-standardised annual rates stratifying by age and sex	Not reported	2005 v. 2004 (pre-ban): Males: 5.69% decrease Females: 6.85% decrease 2006 v. 2005 (post-ban): Males: 10.68% decrease Females: 8.76% decrease (95% CIs: not reported)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Dove et al. (2010) Massachusetts, USA	State-wide comprehensive smoking ban including hospitality venues: 5 Jul. 2004	26,982 AMI deaths in ages ≥35 years in 290 cities/towns without previous local bans and 61 cities/towns with previous local bans 1999-2006	Poisson regression analysis adjusting for linear time trend, season, influenza epidemics, $PM_{2.5}$ air pollution, city/town-specific demographic factors, and stratifying by age, sex, and prior smoking restrictions	7.4% decrease (95% CI: -11.4% to -3.3%)	Cities/towns without prior local smoking bans: 9.9% decrease (95% CI: -14.3% to -5.3%) Cities/towns with prior local smoking bans: 1.4% increase (95% CI: -7.6% to 11.3%)
Mackay et al. (2010a) Scotland	National comprehensive smoking ban including hospitality venues: 26 Mar. 2006	21,415 asthma hospital admissions in ages ≤14 years Jan. 2000-Oct. 2009	Negative binomial regression analysis adjusting for age group, sex, quintile of SES, urban or rural residence, month, and year	Relative to rate on 26 Mar. 2006: 19.5% decrease (95% CI: -22.4% to -16.5%) Net annual change: 15.1% decrease (95% CI: -17.2% to -12.9%)	Net annual change: Males: 15.8% decrease (95% CI: -18.6% to -13.0%) Females: 13.9% decrease (95% CI: -17.4% to -10.4%)
Moraros et al. (2010) Delaware, USA	State-wide comprehensive smoking ban including hospitality venues: 27 Nov. 2002	Hospital admissions for AMI (n=10,648) and asthma (# not reported) in Delaware residents (covered by ban) and AMI (n=2,077) and asthma (# not reported) in non-residents (not covered by ban), ages ≥18 years 1999-2004, excluding Oct.-Dec. 2002	Poisson regression analysis adjusting for linear time trend, season, and growth in resident population	Resident AMI: RR=0.91 (95% CI: 0.87-0.95) Non-resident AMI: RR=0.98 (95% CI: 0.90-1.08) Resident Asthma: RR=0.95 (95% CI: 0.90-0.99) Non-resident Asthma: RR=1.62 (95% CI: 1.41-1.86)	Not reported

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Naiman et al. (2010) Toronto, Ontario, Canada	City-wide smoking ban: Phase I: public places and workplaces: Oct. 1999 Phase II: restaurants and bowling centres: Jun. 2001 Phase III: bars and casinos: Jun. 2004	Hospital admissions (# not reported) for AMI, angina, stroke (ages ≥45 years); asthma (ages ≤64 years), COPD (ages ≥45 years), bronchitis and pneumonia, and three control conditions in Toronto (ban enforced) and two control regions (no ban enforced) Jan. 1996-Apr. 2006	ARIMA with interrupted time-series analysis adjusting for time trend and stratifying by age and sex	Post-Phase II for Toronto: All CV conditions: 39% decrease (95% CI: -40% to -38%) All respiratory conditions: 33% decrease (95% CI: -34% to -32%) Control conditions: no decreases (% not reported) Control regions: All CV conditions: 3.4% decrease (*p*=0.055) All respiratory conditions: 13.5% decrease (*p*=0.239)	Not reported
Sims et al. (2010) England	National comprehensive smoking ban including hospitality venues: 1 Jul. 2007	342,361 AMI hospital admissions in ages ≥18 years Jul. 2002-Sep. 2008	Poisson regression with interrupted time-series analysis adjusting for linear time trend, temperature, influenza epidemics, week, Christmas holidays, and population growth and stratifying by age and sex	2.37% decrease (95% CI: -4.06% to -0.66%)	Males aged <60 years: 3.46% decrease (95% CI: -5.99% to -0.85%) Females aged <60 years: 2.46% decrease (95% CI: -7.62% to 3.00%) Males aged ≥60 years: 3.07% decrease (95% CI: -4.86% to -1.25%) Females aged ≥60 years: 3.82% decrease (95% CI: -6.48% to -1.09%)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Trachsel et al. (2010) Graubuenden, Switzerland	Canton-wide comprehensive smoking ban including hospitality venues: 1 Mar. 2008	654 AMI hospital admissions Mar. 2006-Feb. 2009	Contingency table comparison analysis of cases from two years pre-ban to one year post-ban stratifying by sex, smoking status, residential status, known coronary artery disease, prior AMI, and prior percutaneous coronary intervention (PCI)	22% decrease (*p*<0.05)	Males: 24% decrease (*p*<0.05) Females: 17% decrease (*p*>0.05) Non-smokers: 30% decrease (*p*<0.05) Smokers: 8% decrease (*p*>0.05)
Barone-Adesi et al. (2011) Italy	National comprehensive smoking ban including hospitality venues: 10 Jan. 2005	936,519 ACE hospital admissions Jan. 2002-Nov. 2006	Mixed-effect Poisson regression with interrupted time-series analysis adjusting for long-term trend, season, and all-cause hospitalisation rates and stratifying by age, sex, macro-geographical area, and discharge diagnosis	RR=0.98 (95% CI: 0.97-1.00)	Ages <70 years: RR=0.96 (95% CI: 0.95-0.98) Ages ≥70 years: RR=1.00 (95% CI: 0.99-1.02)
Herman and Walsh (2011) Arizona, USA	State-wide comprehensive smoking ban including hospitality venues: 1 May 2007	Hospital admissions for AMI (n=39,341), angina (n=2,063), stroke (n=47,849), asthma (n=27,451), and four control conditions in 10 counties without previous local smoking bans and 5 counties with previous local smoking bans Jan. 2004-May 2008	Poisson regression analysis adjusting for linear time trend and season and stratifying by prior smoking restrictions	Counties without prior local bans: AMI: 13% decrease (*p*=0.01) Angina: 33% decrease (*p*=0.014) Stroke: 14% decrease (*p*=0.001) Asthma: 22% decrease (*p*<0.001) Counties with prior local bans: AMI: 4% increase (*p*=0.027) Angina: 1% decrease (*p*=0.934) Stroke: 2% decrease (*p*=0.155) Asthma: 4% decrease (*p*=0.035) Control conditions: no decreases (% not reported)	Not reported

Authors, Year, and Location	Smoking Ban Policy and Implementation Date	Study Population and Assessment Period	Analytical Method and Adjustments for Potential Confounders	Overall Post-Ban Health Effects	Subgroup Post-Ban Health Effects*
Shetty et al. (2011) USA	Any state-wide or city-wide smoking restrictions, partial or comprehensive: 1990-2004	AMI deaths and hospital admissions (# not reported) for AMI, asthma, COPD, and one control condition 1993-2004	Multivariate linear regression analysis adjusting for time trend, region-specific indicators, state cigarette taxes, and county-level characteristics in some models and stratifying by age	AMI deaths over entire period: 1.3% increase (95% CI: -1.1% to 3.6%) Hospital admissions one year post-smoking restriction: AMI: 1.8% decrease (95% CI: -6.7% to 3.1%) Asthma: 1.3% decrease (95% CI: -6.5% to 4.0%) COPD: 3.5% decrease (95% CI: -9.2% to 2.1%) Control condition: 0.2% increase (95% CI: -3.6% to 4.1%)	Hospital admissions one year post-smoking restriction in ages 18-64 years: AMI: 0.3% decrease (95% CI: -5.5% to 5.0%) Asthma: 7.6% decrease (95% CI: -13.4% to -1.8%) COPD: 4.9% decrease (95% CI: -13.0% to 3.2%) Control condition: 11.1% increase (95% CI: 2.6% to 19.6%)
Bonetti et al. (2011) Graubünden, Switzerland	Canton-wide comprehensive smoking ban including hospitality venues: 1 Mar. 2008	842 AMI hospital admissions in Graubünden (ban enforced) and 830 AMI hospital admissions in Lucerne (no ban enforced) Mar. 2006-Feb. 2010	Contingency table comparison analysis of cases from two years pre-ban to two years post-ban with a correlation test for air pollution (PM_{10} and NO_2) and stratifying by sex, smoking status, residential status, known coronary artery disease, prior AMI, and prior PCI	Graubünden: 21% decrease ($p<0.05$) Lucerne: 32% increase ($p<0.05$) (data unavailable for first 12-month period of Mar. 2006-Feb. 2007)	Graubünden: Males: 18% decrease ($p<0.05$) Females: 30% decrease ($p<0.05$) Non-smokers: 30% decrease ($p<0.05$) Smokers: 3% decrease ($p>0.05$)
Bruintjes et al. (2011) Greeley, Colorado, USA	City-wide comprehensive smoking ban including hospitality venues and outdoor public places with seating: Dec. 2003	482 AMI hospital admissions in Greeley (ban enforced) and 224 AMI hospital admissions in surrounding zip code areas (no ban enforced) Jul. 2002-Jun. 2006	Poisson regression analysis adjusting for linear time trend, season, and population growth and stratifying by smoking status and AMI type	Greeley: Relative Risk=0.73 (95% CI: 0.59-0.90) Surrounding areas: Relative Risk=0.83 (95% CI: 0.61-1.14)	Greeley: Non-smokers: Relative Risk=0.86 (95% CI: 0.67-1.09) Smokers: Relative Risk=0.44 (95% CI: 0.29-0.65)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Gupta et al. (2011) Kanawha County, West Virginia, USA	County-wide partial smoking ban in public places:1995 Increased penalties for violations: 2000 Amended to include restaurants: 2004	14,245 ACS hospital admissions in ages ≥18 years Jan. 2000-Sep. 2008	Poisson regression analysis adjusting for age, sex, year, season, smoking status, and history of diabetes	Immediate change post-ban including restaurants: RR=1.02 (95% CI: 0.92-1.12)	Post-ban trends: Non-smoking males: RR=1.01 (95% CI: 0.95-1.07) Non-smoking females: RR=1.00 (95% CI: 0.93-1.06) Smoking Males: RR=0.93 (95% CI: 0.88-1.00) Smoking Females: RR=0.95 (95% CI: 0.88-1.03)
Hahn et al. (2011) Lexington-Fayette County, Kentucky, USA	County-wide partial smoking ban excluding manufacturing facilities and government worksites: 27 Apr. 2004	2,692 AMI hospital discharges in ages ≥35 years 2001-2006	Poisson regression analysis adjusting for time trend, county-specific demographic factors, season, smoking prevalence, age and sex	Not reported	Males: Relative Risk=1.11 (95% CI: 0.91-1.36) Females: Relative Risk=0.77 (95% CI: 0.62-0.96)
Villalbi et al. (2011) Spain	National partial smoking ban excluding bars, restaurants, and night clubs: 1 Jan. 2006	90,382 AMI deaths in ages ≥35 years 2004-2007	Poisson regression analysis adjusting for age and stratifying by sex	One year post-ban: Relative Risk=0.90 (95% CI: 0.88-0.92) Two years post-ban: Relative Risk=0.86 (95% CI: 0.84-0.88)	Two years post-ban: Males: Relative Risk=0.86 (95% CI: 0.83-0.88) Females: Relative Risk=0.86 (95% CI: 0.84-0.89)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Rodu et al. (2012) California (CA), Utah (UT), South Dakota (SD), Delaware (DE), Florida (FL), and New York (NY), USA	CA: 1 Jan. 1995 (partial) UT: 1 Jan. 1995 (partial) SD: 1 Jul. 2002 (partial) DE: 27 Nov. 2002 (comprehensive) FL: 1 Jul. 2003 (comprehensive) NY: 24 Jul. 2003 (comprehensive)	39,962 AMI deaths in ages ≥45 years in 6 states with bans and 44 states without bans (# deaths not reported) 1995-2004	Comparison of observed vs. expected rates based upon three year average change pre-ban to one year post-ban for each respective state adjusting for age	1995: CA: 2.0% decrease (*p*=0.16) UT: 7.7% decrease (*p*=0.43) Other 48 states: 3.9% decrease (*p*=0.56) 2003: SD: 8.9% increase (*p*=0.007) DE: 8.1% decrease (*p*=0.89) Other 46 states: 7.2% decrease (*p*<0.0002) 2004: FL: 8.8% decrease (*p*=0.04) NY: 12.0% decrease (*p*<0.0002) Other 44 states: 9.8% decrease (*p*<0.0002)	Not reported
Ferrante et al. (2012) Buenos Aires city and Santa Fe province, Argentina	Santa Fe province-wide comprehensive smoking ban including hospitality venues: Aug. 2006 Buenos Aires city-wide partial smoking ban excluding bars and restaurants: Oct. 2006	8,425 ACS hospital admissions in Santa Fe province (full ban enforced) and 6,320 ACS hospital admissions in Buenos Aires city (partial ban enforced) in ages ≥18 years 2004-2008	Multiple linear regression with interrupted time-series analysis adjusting for linear time trend, season, age, and sex	Santa Fe immediate change: 2.5/100,000 decrease (95% CI: -4.74 to -0.26) Santa Fe trend: 0.26/100,000 decrease per month (95% CI: -0.39 to -0.13) Buenos Aires immediate change: 1.74/100,000 increase (95% CI: -1.43 to 4.92) Buenos Aires trend: 0.01/100,000 increase (95% CI: -0.12 to 0.14)	Not reported

Authors, Year, and Location	Smoking Ban Policy and Implementation Date	Study Population and Assessment Period	Analytical Method and Adjustments for Potential Confounders	Overall Post-Ban Health Effects	Subgroup Post-Ban Health Effects*
Sebrié et al. (2012) Uruguay	National comprehensive smoking ban including hospitality venues: 1 Mar. 2006	7,949 AMI hospital admissions in ages ≥20 years Mar. 2004 to Feb. 2008	Multiple linear, ARIMA, and negative binomial regression analyses adjusting for season and stratifying by age, sex, and public v. private hospital	Multiple linear: -35.9±10.1 (*p*=0.001) or 22% decrease ARIMA: -29.56±7.87 (*p*<0.001) Negative binomial: RR=0.84 (95% CI: 0.78-0.91)	Males: -23.9±8.8 (*p*=0.012) or 20% decrease Females: -12.5±4.4 (*p*=0.008) or 19% decrease
Cronin et al. (2012) Cork and Kerry Counties, Ireland	National comprehensive smoking ban including hospitality venues: 29 Mar. 2004	4,277 ACS hospital admissions and out-of-hospital coronary deaths (# not reported) in ages ≥18 years Mar. 2003-Mar. 2007	Poisson regression analysis stratifying by sex, smoking status, and ACS type	Admissions: 1st post-ban year v. pre-ban: 12% decrease (*p*=0.002) 2nd year v. 1st post-ban year: 2% decrease (*p*>0.1) 3rd year v. 2nd post-ban year: 13% decrease (*p-value* not reported) Out-of-hospital deaths: 6.5% decrease over study period (*p-value* not reported)	Rates for 1st post-ban year v. pre-ban: Males: 281.5 v. 233.5/100,000 (*p*=0.0011) Females: 130.7 v. 122.4/100,000 (*p-value* not reported)
Sargent et al. (2012) Germany	National partial smoking ban allowing individual state legislation for hospitality venues: 1 Sep. 2007	79,928 angina hospital admissions and 39,224 AMI hospital admissions in ages ≥30 years 2004-2008	Logistic regression analysis stratifying by age, sex, and occupation and change point time-series linear regression adjusting for age and sex	1-year post-ban: Angina: 13.28% decrease (95% CI: -18.36% to -8.19%) AMI: 8.58% decrease (95% CI: -12.17% to -4.99%)	1-year post-ban for Angina: Males: 14.32% decrease (95% CI: -19.81% to -8.83%) Females: 10.92% decrease (95% CI: -16.53% to -5.31%) 1-year post-ban for AMI: Males: 9.58% decrease (95% CI: -14.06% to -5.09%) Females: 4.54% decrease (95% CI: -9.79% to 0.71%)

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Kent et al. (2012) Ireland	National comprehensive smoking ban including hospitality venues: 29 Mar. 2004	44,321 emergency hospital admissions for pulmonary illness, 16,839 admissions for ACS and 10,743 admissions for cerebrovascular syndromes in ages 20-69 years 2002-2003 and 2005-2006	Poisson log-linear and negative binomial regression analyses adjusting for PM_{10}, $PM_{2.5}$, temperature, influenza-like-illness rate, influenza case rate and stratifying by age	Pulmonary illness: Relative Risk=0.85 (95% CI: 0.72-0.99) Pneumonia: Relative Risk=0.71 (95% CI: 0.52-0.98) Asthma: Relative Risk=0.60 (95% CI: 0.39-0.91) COPD: Relative Risk=1.18 (95% CI: 0.86-1.60) ACS: Relative Risk=0.82 (95% CI: 0.70-0.97) Stroke: Relative Risk=0.93 (95% CI: 0.73-1.20)	Pulmonary illness: Age 20-29: Relative Risk=0.62 (95% CI: 0.49-0.78) Age 30-39: Relative Risk=0.74 (95% CI: 0.60-0.93) Age ≥40: No effects detected (point estimates not reported)
Hurt et al. (2012) Olmsted County, Minnesota, USA	Ordinance 1: County-wide partial smoking ban in restaurants: 1 Jan. 2002 Ordinance 2: Comprehensive workplace smoking ban including bars: 1 Oct. 2007	717 hospital admissions for MI and 514 out-of-hospital sudden cardiac deaths (SCD) Jul. 2000-Dec. 2001 and Oct. 2007-Apr. 2009	Poisson regression analysis adjusting for age and sex	18 months before and after: Ordinance 1: MI: Relative Risk=0.96 (95% CI: 0.78-1.18) SCD: Relative Risk=1.01 (95% CI: 0.80-1.27) Ordinance 2: MI: Relative Risk=0.66 (95% CI: 0.53-0.82) SCD: Relative Risk=1.17 (95% CI: 0.91-1.51)	Not reported

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Adams et al. (2013) 50 States, USA	Any workplace smoking ban measured by the proportion of the state population covered 2000-2005	MI deaths (# not reported) in 34 states with workplace bans and 16 states without workplace smoking bans 2000-2005	Least squares estimation, Poisson regression, and negative binomial regression analyses adjusting for state population growth, cigarette taxes, per-capita income, unemployment rates, non-CV deaths, and linear time trends in some models, stratifying by age	Not reported	Age 25-54 years: Least squares: 16.8% decrease ($p<0.01$) as state smoking ban coverage increases from 0-100% Poisson: 14.6% decrease ($p<0.01$) Negative binomial: 14.5% decrease ($p<0.01$)

*Selected effects presented due to space limitations

Table 2.2: Groupings of Primary Study Characteristics for Narrative Synthesis

Study Groupings	N	%	Author, Year
Year of Publication (n=37)			
1990-1999	0	0	
2000-2009	15	41	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Khuder et al., 2007; Seo and Torabi et al., 2007; Cesaroni et al., 2008; Lemstra et al., 2008; Pell et al., 2008; Rayens et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Villalbí et al., 2009
2010-January 2013	22	59	Dove et al., 2010; Mackay et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Herman and Walsh et al., 2011; Shetty et al., 2011; Bonetti et al., 2011; Bruintjes et al., 2011; Rodu et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Villalbí et al., 2011; Ferrante et al., 2012; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012; Hurt et al., 2012; Adams et al., 2013
Study Design (n=37)			
Prospective	3	8	Pell et al., 2008; Trachsel et al., 2010; Bonetti et al., 2011
Retrospective	34	92	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Khuder et al., 2007; Seo and Torabi et al., 2007; Cesaroni et al., 2008; Lemstra et al., 2008; Rayens et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Dove et al., 2010; Mackay et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Sims et al., 2010; Barone-Adesi et al., 2011; Herman and Walsh et al., 2011; Shetty et al., 2011; Bruintjes et al., 2011; Rodu et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Villalbí et al., 2011; Ferrante et al., 2012; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012; Hurt et al., 2012; Adams et al., 2013
Region (n=37)			
Australia/Oceania	1	3	Barnett et al., 2009
Europe	15	41	Barone-Adesi et al., 2006; Cesaroni et al., 2008; Pell et al., 2008; Vasselli et al., 2008; Gasparrini et al., 2009; Villalbí et al., 2009; Mackay et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Bonetti et al., 2011; Villalbí et al., 2011; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012
North America	19	51	Sargent et al., 2004; Bartecchi et al., 2006; Juster et al., 2007; Khuder et al., 2007; Seo and Torabi et al., 2007; Lemstra et al., 2008; Rayens et al., 2008; CDC, 2009; Dove et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Bruintjes et al., 2011; Rodu et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Hurt et al., 2012; Adams et al., 2013
South America	2	5	Ferrante et al., 2012; Sebrié et al., 2012
Smoking Ban Policy (n=37)			
Comprehensive	24	65	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Cesaroni et al., 2008; Lemstra et al., 2008; Pell et al., 2008; Rayens et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Dove et al., 2010; Mackay et al., 2010; Moraros et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Herman and Walsh et al., 2011; Bonetti et al., 2011; Bruintjes et al., 2011; Sebrié et al., 2012; Cronin et al., 2012; Kent et al., 2012
Partial	5	14	Khuder et al., 2007; Villalbí et al., 2009; Hahn et al., 2011; Villalbí et al., 2011; Sargent et al., 2012

Study Groupings	N	%	Author, Year
Stepwise Partial to Comprehensive	3	8	Seo and Torabi et al., 2007; Naiman et al., 2010; Gupta et al., 2011;
Both Comprehensive and Partial	5	14	Shetty et al., 2011; Rodu et al., 2011; Ferrante et al., 2012; Hurt et al., 2012; Adams et al., 2013
Population Covered by Ban (n=39)†			
National	15	38	Barone-Adesi et al., 2006; Cesaroni et al., 2008; Pell et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Mackay et al., 2010; Sims et al., 2010; Barone-Adesi et al., 2011; Villalbí et al., 2011; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012
Regional/State-wide	10	26	Juster et al., 2007; Dove et al., 2010; Moraros et al., 2010; Trachsel et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Bonetti et al., 2011; Rodu et al., 2011; Ferrante et al., 2012; Adams et al., 2013
County-wide	5	13	Seo and Torabi et al., 2007; Rayens et al., 2008; Gupta et al., 2011; Hahn et al., 2011; Hurt et al., 2012
City-wide	9	23	Sargent et al., 2004; Bartecchi et al., 2006; Khuder et al., 2007; Lemstra et al., 2008; CDC, 2009; Naiman et al., 2010; Shetty et al., 2011; Bruintjes et al., 2011; Ferrante et al., 2012
Outcome (n=42)‡			
Cardiovascular	35	83	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Khuder et al., 2007; Seo and Torabi et al., 2007; Cesaroni et al., 2008; Lemstra et al., 2008; Pell et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Dove et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Herman and Walsh et al., 2011; Shetty et al., 2011; Bonetti et al., 2011; Bruintjes et al., 2011; Rodu et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Villalbí et al., 2011; Ferrante et al., 2012; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012; Hurt et al., 2012; Adams et al., 2013
*Morbidity (n=41)**	*31*	*74*	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Khuder et al., 2007; Seo and Torabi et al., 2007; Cesaroni et al., 2008; Lemstra et al., 2008; Pell et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Moraros et al., 2010; Naiman et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Herman and Walsh et al., 2011; Shetty et al., 2011; Bonetti et al., 2011; Bruintjes et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Ferrante et al., 2012; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012; Kent et al., 2012; Hurt et al., 2012
Acute Coronary Events (ACE)	*2*	*5*	Cesaroni et al., 2008; Barone-Adesi et al., 2011
Acute Coronary Syndromes (ACS)	*5*	*12*	Pell et al., 2008; Ferrante et al., 2012; Gupta et al., 2011; Cronin et al., 2012; Kent et al., 2012
Acute Myocardial Infarction (AMI)/Myocardial Infarction (MI)	*24*	*59*	Sargent et al., 2004; Bartecchi et al., 2006; Barone-Adesi et al., 2006; Juster et al., 2007; Seo and Torabi et al., 2007; Lemstra et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; CDC, 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Moraros et al., 2010; Naiman et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Bonetti et al., 2011; Bruintjes et al., 2011; Hahn et al., 2011; Sebrié et al., 2012; Sargent et al., 2012; Kent et al., 2012; Hurt et al., 2012
Angina	*4*	*10*	Naiman et al., 2010; Herman and Walsh et al., 2011; Sargent et al., 2012; Kent et al., 2012
Coronary Heart Disease (CHD)	*1*	*2*	Khuder et al., 2007

Study Groupings	N	%	Author, Year
Stroke	*4*	*10*	Juster et al., 2007; Naiman et al., 2010; Herman and Walsh et al., 2011; Kent et al., 2012
Transient Ischemic Attack	*1*	*2*	Kent et al., 2012
*Mortality (n=12)***	*11*	*26*	Cesaroni et al., 2008; Pell et al., 2008; CDC, 2009; Gasparrini et al., 2009; Dove et al., 2010; Shetty et al., 2011; Rodu et al., 2011; Villalbí et al., 2011; Cronin et al., 2012; Hurt et al., 2012; Adams et al., 2013
Acute Coronary Events (ACE)	*1*	*8*	Cesaroni et al., 2008
Acute Coronary Syndromes (ACS)	*2*	*17*	Pell et al., 2008; Cronin et al., 2012
Acute Myocardial Infarction (AMI)/Myocardial Infarction (MI)	*8*	*67*	CDC, 2009; Gasparrini et al., 2009; Dove et al., 2010; Shetty et al., 2011; Rodu et al., 2011; Villalbí et al., 2011; Hurt et al., 2012; Adams et al., 2013
Sudden Cardiac Deaths (SCD)	*1*	*8*	Hurt et al., 2012
Respiratory	7	17	Rayens et al., 2008; Mackay et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Kent et al., 2012
*Morbidity (n=15)****	*7*	*100*	Rayens et al., 2008; Mackay et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Kent et al., 2012
Asthma	*7*	*47*	Rayens et al., 2008; Mackay et al., 2010; Moraros et al., 2010; Naiman et al., 2010; Herman and Walsh et al., 2011; Shetty et al., 2011; Kent et al., 2012
Bronchitis/ Pneumonia	*2*	*13*	Naiman et al., 2010; Kent et al., 2012
Chronic Obstructive Pulmonary Disease (COPD)	*3*	*20*	Naiman et al., 2010; Shetty et al., 2011; Kent et al., 2012
Lower Respiratory Tract Infection	*1*	*7*	Kent et al., 2012
Pulmonary Disease	*1*	*7*	Kent et al., 2012
Spontaneous Pneumothorax	*1*	*7*	Kent et al., 2012
Mortality	*0*	*0*	
Effect Modification Analyses (n=37)			
Age	19	51	Barone-Adesi et al., 2006; Cesaroni et al., 2008; Pell et al., 2008; Rayens et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; Villalbí et al., 2009; Dove et al., 2010; Mackay et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Shetty et al., 2011; Gupta et al., 2011; Villalbí et al., 2011; Sebrié et al., 2012; Sargent et al., 2012; Kent et al., 2012; Adams et al., 2013
Sex	20	54	Barone-Adesi et al., 2006; Cesaroni et al., 2008; Pell et al., 2008; Rayens et al., 2008; Vasselli et al., 2008; Barnett et al., 2009; Gasparrini et al., 2009; Villalbí et al., 2009; Dove et al., 2010; Mackay et al., 2010; Sims et al., 2010; Trachsel et al., 2010; Barone-Adesi et al., 2011; Bonetti et al., 2011; Gupta et al., 2011; Hahn et al., 2011; Villalbí et al., 2011; Sebrié et al., 2012; Cronin et al., 2012; Sargent et al., 2012

Study Groupings	N	%	Author, Year
Smoking Status	8	22	Seo and Torabi et al., 2007; Pell et al., 2008; Barnett et al., 2009; Trachsel et al., 2010; Bonetti et al., 2011; Bruintjes et al., 2011; Gupta et al., 2011; Cronin et al., 2012
Socioeconomic Indicator(s)	3	8	Cesaroni et al., 2008; Barnett et al., 2009; Mackay et al., 2010

†Two studies evaluated both regional/state-wide and city-wide smoking bans
‡Five studies assessed both cardiovascular and respiratory outcomes
*Ten studies assessed multiple outcomes of cardiovascular morbidity
**One study assessed multiple outcomes of cardiovascular mortality
***Three studies assessed multiples outcomes of respiratory morbidity

Study designs were predominantly retrospective with only three studies employing a prospective design (Bonetti et al., 2011; Pell et al., 2008; Trachsel et al., 2010). Most of the studies evaluated populations in either North America (n=19) or Europe (n=15), with only two studies assessing populations in South America (Ferrante et al., 2012; Sebrié et al., 2012) and one study in Australia/Oceania (Barnett et al., 2009).

The types of smoking ban policies evaluated in the primary studies varied in both modes of implementation and comprehensiveness of population coverage. Most of the studies (n=24) assessed comprehensive smoking legislation that prohibited smoking in workplaces, public places, and hospitality venues such as bars and restaurants. Other studies assessed either partial smoking bans, with legislative exclusions for venues such as restaurants and bars, or smoking bans with stepwise implementation from partial to more comprehensive coverage. Five studies assessed both comprehensive and partial smoking bans (Adams et al., 2013; Ferrante et al., 2012; Hurt et al., 2012; Rodu et al., 2012; Shetty et al., 2011), but only one used the study design for the specific purpose of comparing effects between the two intervention types (Ferrante et al., 2012).

Relevant evidence was found for three categories of health outcomes: cardiovascular morbidity (n=31), cardiovascular mortality (n=11), and respiratory morbidity (n=7), with several studies assessing multiple outcomes (n=12). Four studies assessed post-ban effects on stroke morbidity, but no studies assessed stroke mortality. Additionally, no studies of respiratory mortality were identified. A specific diagnosis of AMI/MI was the most commonly analysed outcome both in studies of cardiovascular morbidity (n=24) and mortality (n=8). All studies of respiratory morbidity analysed asthma as a specific diagnosis (n=7), with 3 studies analysing multiple respiratory diagnoses. Evidence of a protective association between smoking ban policies and health outcomes was demonstrated in 33 of 37 studies (89%).

Out of 35 studies assessing cardiovascular outcomes, 31 showed post-ban reductions either in the overall population or in specific subgroups, while four studies showed no effects (Gasparrini et al., 2009; Gupta et al., 2011; Rodu et al., 2012; Shetty et al., 2011). One of these studies, an assessment of a stepwise-implemented county-wide smoking ban in West Virginia, USA, found consistent reductions in ACS admissions over the study period, but did not find significantly different effects following the amendment of the ordinance to ban smoking in restaurants (Gupta et al., 2011). The starting point of the assessment period was five years following implementation of the initial partial ban, and no data were available to assess long-term changes that may have occurred in population exposure to secondhand smoke.

Three studies did not observe significant decreases in post-ban AMI rates (Gasparrini et al., 2009; Rodu et al., 2012; Shetty et al., 2011). The first study, which assessed hospital admissions and deaths in the population of Tuscany, demonstrated a post-ban decrease in rates of AMI with the use of a linear time trend in regression models; however, no effect was observed with the use of a non-linear time trend (Gasparrini et al., 2009). The second study, which assessed the effects of workplace or any public place smoking restrictions on hospital admissions and deaths in all U.S. states, showed no effects on AMI (Shetty et al., 2011). However, when designating intervention areas as covered by a smoking ban policy, the study employed a modified version of the Americans for Nonsmokers' Rights (ANR) classification scheme to also include areas that the ANR does not consider to be covered by a qualified ban. This potential misclassification may have resulted in an underestimation of effects. In contrast, a similar analysis of smoking restrictions in U.S. states, classified according to the ANR scheme, found significant post-ban reductions in AMI mortality for ages 25-54 years when assessing the effects of smoking bans that did not allow exclusions for smoking in any indoor areas (Adams et al., 2013). The third study, which assessed the AMI mortality effects of both partial and comprehensive smoking bans in six U.S. states, demonstrated significant post-ban mortality reductions in two states with comprehensive smoking bans, though effects were not significantly different from those in the non-ban control states (Rodu et al., 2012). These authors acknowledged unrestricted grant support from tobacco manufacturers.

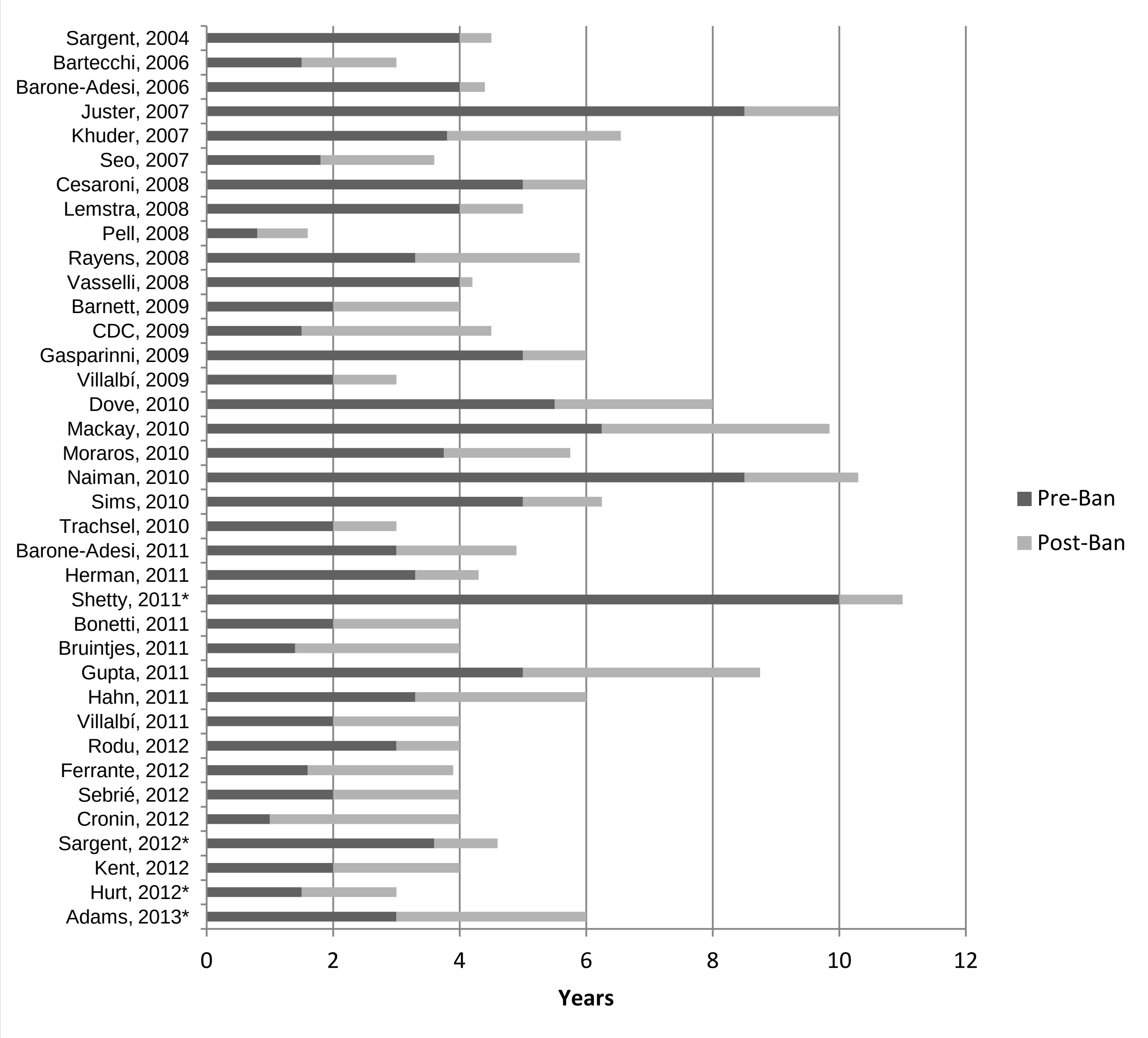
For respiratory outcomes, all seven studies demonstrated significant post-ban reductions in at least one population subgroup (Herman & Walsh, 2011; Kent et al., 2012; Mackay et al., 2010a;

Moraros et al., 2010; Naiman et al., 2010; Rayens et al., 2008; Shetty et al., 2011), with children also benefitting from post-ban reductions in asthma morbidity (Mackay et al., 2010a; Rayens et al., 2008). Two studies assessing comprehensive smoking ban effects on lung infection due to bronchitis and/or pneumonia found important post-ban reductions (Kent et al., 2012; Naiman et al., 2010).

Post-ban effects for COPD morbidity were less clear. A study assessing the effects of the province-wide smoking ban in Ontario, Canada, reported no effects on COPD hospital admissions following the implementation of the partial workplace smoking ban; however, post-ban decreases were detected following the amendment of the ordinance to include restaurants (Naiman et al., 2010). Kent et al. (2012) assessed the effects of the national Irish workplace smoking ban on emergency admissions for COPD and found no post-ban effects; however, the authors postulated that persons at-risk for COPD exacerbations may not be exposed to secondhand smoke in workplaces. Additionally, the Irish workplace smoking ban excludes coverage for nursing homes ("Citizens Information Ireland," 2012); therefore, many persons with COPD may not have experienced post-ban reductions in secondhand smoke exposure. A study assessing the effects of U.S. workplace smoking bans showed no effects on hospital admissions due to COPD exacerbations (Shetty et al., 2011), but the potential misclassification of ban areas in this study may have impacted findings.

Figure 2.2 displays the pre- and post-ban assessment periods for each study. The range of post-ban follow-up was two months to 3.75 years with a mean of 1.78 years (Standard Deviation=0.74). Two studies (Bonetti et al., 2011; CDC, 2009) were extended analyses of previously published studies (Bartecchi et al., 2006; Trachsel et al., 2010), conducted to examine effects after a lengthened post-ban assessment period.

Figure 2.2: Pre- and Post-Ban Assessment Periods for Primary Studies of Smoking Ban Health Effects



*Approximate pre-ban period for studies assessing multiple interventions

The critical appraisal of studies shown in Table 2.3 demonstrates that adjustment for potential confounding factors, either through inclusion as a covariate in regression analyses or through the use of stratification, varied widely between studies with a per study range of zero to ten factors considered. Most commonly, adjustments were made for sex (n=27), age (n=25) and season (n=17). Through discussion and reference to other publications, the majority of studies (n=34) addressed contextual factors that may also operate as potential confounders. Furthermore, twenty studies conducted additional analyses for factors such as ban compliance, public support for the ban, demographic changes, economic impacts, smoking prevalence, cigarette sales, and changes in potential risk factors for cardiovascular and respiratory disease such as hypercholesterolemia, obesity, and diabetes (WHO, 2007a, 2007b).

Twenty-three studies assessed for post-ban effect modification by age (n=19), sex (n=20), and/or smoking status (n=8). Results by age and sex were generally divided with 47% and 40% of studies respectively finding no differences in effects, and the remaining studies showing greater post-ban benefits split almost equally between the younger age groups, older age groups, males, and females. Five of eight (63%) studies assessing effects by smoking status demonstrated that non-smokers experienced greater post-ban benefits than smokers.

Several studies validated post-ban health effects by comparing outcomes in a population covered by a smoking ban with a population not covered by a smoking ban (n=9) or in a population covered by a partial smoking ban (Ferrante et al., 2012). These comparisons were most readily conducted in studies of smoking bans with local or regional coverage versus smoking bans with national coverage. Additional comparative techniques included the assessment of resident and non-resident hospital admissions within the smoking ban enforcement area (Bonetti et al., 2011; Moraros et al., 2010; Trachsel et al., 2010) or smoking-related versus non-smoking-related hospital admissions (Herman & Walsh, 2011; Shetty et al., 2011).

Table 2.3: Critical Appraisal of Empirical Studies Assessing the Health Effects of Smoking Ban Policies

Authors and Year	**Study Type**	**Elements of Study Design**†	**Control for Potential Confounders**	**Consideration of Contextual Confounders**‡*	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Sargent et al. (2004)	Retrospective	A, B, D	Season		Changes in outcome diagnostic criteria	American Cancer Society, American Heart Association, American Lung Association of the Northern Rockies, Robert Wood Johnson Foundation, National Cancer Institute, American Legacy Foundation	Small study population; 6-month intervention period
Bartecchi et al. (2006)	Retrospective	A, B, D	Season	Economic and healthcare delivery changes,* smoking prevalence*	Out-of hospital deaths, compared control population by age, sex	Colorado Department of Health and Environment	
Barone-Adesi et al. (2006)	Retrospective	A, B	Season, age, sex	Smoking prevalence, mean cigarettes smoked per day	Long-term trend in admissions	San Paolo Foundation, Italian Association for Cancer Research	5-month intervention period
Juster et al. (2007)	Retrospective	A, B, C	Season, linear time trend, geographic differences in admissions, prior smoking restrictions, county-level CV risk factors, age		Smoking prevalence	CDC, New York State Department of Health	
Khuder et al. (2007)	Retrospective	A, B, C, D	Matched control city on age, sex, population size	Diet,* physical activity*	Non-smoking related admissions	Ohio Tobacco Prevention Foundation	Size of study population not reported
Seo and Torabi (2007)	Retrospective	A, B, D	Season, co-morbidity, past cardiac history, smoking status Matched control county on race, income, CV mortality, population size			American Institutes for Research, Indiana Tobacco Prevention and Cessation	Small study population

Authors and Year	Study Type	Elements of Study Design†	Control for Potential Confounders	Consideration of Contextual Confounders‡*	Sensitivity Analyses	Funding/Potential Conflict of Interest	Comments
Cesaroni et al. (2008)	Retrospective	A, B, C	Linear time trend, PM_{10} air pollution, temperature, influenza epidemics, holidays, age, sex, SES	Smoking prevalence, cigarette sales, use of statins,* sales of nicotine-replacement products, * changes in diagnostic criteria*	All-cause hospitalisation rates	Lazio Region Health Authority	No suitable comparison population was available
Lemstra et al. (2008)	Retrospective	A	Age, sex, prior AMI	Smoking prevalence, public support for the ban, ban compliance		Canadian Institutes of Health Research, National Cancer Institute of Canada, Canadian Cancer Society, Heart and Stroke Foundation, Canadian Lung Association	
Pell et al. (2008)	Prospective	A, B, D	Season, serum cotinine-confirmed smoking status, age, sex Comparison population similar in lifestyle, climate, clinical care	Self-reported SHS exposure in non-smokers, ban compliance,* displacement of smoking into homes*	Admission trends, out-of-hospital deaths	NHS Health Scotland, British Heart Foundation, Atherogenics, Merck Sharp and Dohme, Novartis, Medtronic, Cordis	
Rayens et al. (2008)	Retrospective	A, B	Season, time trend, age, sex	Indoor air pollution,* SHS exposure,* respiratory symptoms,* worker migration*	First-order autoregressive model, omitted one pre-ban year with greatest increase in cases	Flight Attendant Medical Research Institute, National Institutes of Health, GlaxoSmithKline, Pfizer, Boehringer-Ingelheim, Novartis	
Vasselli et al. (2008)	Retrospective	A, B, C	Age, sex, region	SHS exposure,* smoking prevalence,* per capita cigarette consumption*		No conflict of interest statement	2-month intervention period

Authors and Year	**Study Type**	**Elements of Study Design**[†]	**Control for Potential Confounders**	**Consideration of Contextual Confounders**[‡*]	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Barnett et al. (2009)	Retrospective	A, B	Age, sex, smoking status, neighbourhood social deprivation (SES)	Indoor air quality,* smoking cessation attempts,* use of statins,* excess winter mortality, *diet,* changes in diagnostic criteria*		No conflict of interest statement	
CDC (2009)	Retrospective	A, B, D		Smoking prevalence,* age and sex-specific distribution of AMI for case and control populations	Admission trends, out-of hospital deaths	No conflict of interest statement	Extended analysis of Bartecchi *et al.* (2006)
Gasparrini et al. (2009)	Retrospective	A, B, C	Season, linear time trend, non-linear time trend, age, sex	SHS exposure,* CV risk factors,* clinical care,* changes in diagnostic criteria*	Various temporal trends and seasonal effects	No conflict of interest statement	
Villalbi et al. (2009)	Retrospective	A, B	Age, sex	SHS exposure,* smoking prevalence,* clinical care,* changes in immigrant population*		No conflict of interest statement	
Dove et al. (2010)	Retrospective	A, B, C	Season, linear time trend, influenza epidemics, $PM_{2.5}$ air pollution, SES, prior smoking restrictions, age, sex	Cigarette sales tax,* cardiac defibrillators in public places,* changes in diagnostic criteria,* cholesterol screening,* SHS exposure,* ban compliance*		National Institute of Environmental Health Sciences	
Mackay et al. (2010a)	Retrospective	A, B, C	Age, sex, SES, urban or rural residence, month, year, region, population growth	SHS exposure,* bar worker respiratory symptoms,* displacement of smoking into homes,* educational campaigns,* clinical care changes*	Out-of-hospital deaths	NHS Health Scotland, UK Department of Health	

Authors and Year	**Study Type**	**Elements of Study Design**†	**Control for Potential Confounders**	**Consideration of Contextual Confounders**‡*	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Moraros et al. (2010)	Retrospective	A, B, C, D	Season, linear time trend, population growth, residential status	Changes in diagnostic criteria,* non-linear time trends,* incremental ban implementation*		No conflict of interest statement	Size of study population unable to be determined; 'rate' incorrectly used instead of 'count'
Naiman et al. (2010)	Retrospective	A, B, C, D	Time trend, age, sex	Demographics, smoking status, and SHS exposure of intervention and comparison populations, incremental ban implementation, other restrictions on tobacco sales and advertising,* smokers' choice to not visit restaurants*		Ontario Ministry of Health and Long-Term Care	
Sims et al. (2010)	Retrospective	A, B, C	Linear time trend, temperature, influenza epidemics, week, Christmas holidays, population growth, age, sex	SHS exposure,* changes in diagnostic criteria*	False ban dates	UK Department of Health, UK Centre for Tobacco Control, UKRC Public Health Research, British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council	No suitable comparison population was available
Trachsel et al. (2010)	Prospective	A, B, D	Sex, smoking status, residential status, known coronary artery disease, prior AMI, prior percutaneous coronary intervention (PCI)	Admission trends, population growth, smoking prevalence,* SHS exposure,* lipid-lowering drugs*		Department of Internal Medicine, Kantonsspital Graubuenden	

Authors and Year	**Study Type**	**Elements of Study Design**†	**Control for Potential Confounders**	**Consideration of Contextual Confounders**‡*	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Barone-Adesi et al. (2011)	Retrospective	A, B, C	Season, long-term trend, all-cause hospitalisation rates, age, sex, macro-geographical area, discharge diagnosis	Changes in diagnostic criteria, ban compliance,* SHS exposure,* smoking prevalence,* individual CV risk factors,* changes in clinical care*		San Paolo Foundation, Piedmont Region	
Herman and Walsh (2011)	Retrospective	A, B, C, D	Season, linear time trend, prior smoking restrictions	Population growth, economic impacts		Arizona Department of Health Services Bureau of Tobacco and Chronic Disease	
Shetty et al. (2011)	Retrospective	C, D	Time trend, age, SES	Region-specific indicators, state cigarette taxes, county-level characteristics, displacement of smoking into homes, SHS exposure*	Counties where ban-covered population increased by ≥50%, states with highest smoking prevalence, comprehensive v. partial bans	U.S. Veterans Affairs in Ambulatory Care Practice and Research, U.S. National Institute on Aging	Possible ban misclassification; study population size and assessment period unable to be determined
Bonetti et al. (2011)	Prospective	A, B, D	Sex, smoking status, residential status, known CAD, prior AMI, prior PCI and/or coronary artery bypass graft surgery	Air pollution (PM_{10} and NO_2), sales of lipid-lowering drugs, admission trends		Department of Internal Medicine, Kantonsspital Graubuenden	Extended analysis of Trachsel *et al.* (2010)
Bruintjes et al. (2011)	Retrospective	A, B, C	Season, linear time trend, population growth, smoking status, AMI type (STEMI vs. NSTEMI)	Demographics and health status (BMI, co-morbidities) of comparison population, ban compliance,* smoking prevalence,* SHS exposure,* out-of-hospital deaths,* ageing population*		Colorado Department of Health and Environment	

Authors and Year	**Study Type**	**Elements of Study Design**[†]	**Control for Potential Confounders**	**Consideration of Contextual Confounders**[‡*]	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Gupta et al. (2011)	Retrospective	A, B, C	Age, sex, year, season, smoking status, history of diabetes	Incremental ban implementation, CVD risk factors (obesity, physical activity, hypertension, etc.), smoking prevalence, use of smokeless tobacco,* cigarette sales tax*	AMI compared to all ACS	American Lung Association	No suitable comparison population was available
Hahn et al. (2011)	Retrospective	A, B, C	Time trend, county-specific demographic factors, season, smoking prevalence, age and sex	Smoking prevalence,* CVD risk factors*, SHS exposure,* indoor air quality,* migration	First-order autoregressive time-series model	Flight Attendant Medical Research Institute	No suitable comparison population was available; unable to examine differences by race/ethnicity
Villalbi et al. (2011)	Retrospective	A, B	Age, sex	Ban compliance,* SHS exposure,* indoor nicotine concentration,* smoking prevalence,* changes in clinical care*		Centro de Investigación Biomédica en Red Epidemiología y Salud Pública	No suitable comparison population was available
Rodu et al. (2012)	Retrospective	A, B, C, D	Age	Prior smoking restrictions*		Swedish Match AB, Reynolds American Inc. Services Company Altria Client Services, British American Tobacco	No adjustment for many potential confounders between states

Authors and Year	Study Type	Elements of Study Design†	Control for Potential Confounders	Consideration of Contextual Confounders‡*	Sensitivity Analyses	Funding/Potential Conflict of Interest	Comments
Ferrante et al. (2012)	Retrospective	A, B, C, D	Season, linear time trend, age, sex	Smoking prevalence, ban compliance, SHS exposure, smoking cessation attempts, daily cigarette consumption, gradual ban implementation,* ban on tobacco advertisement*		None to declare	
Sebrié et al. (2012)	Retrospective	A, B	Season, age, sex, public v. private hospital	Admission trends, SHS exposure,* indoor air quality,* ban compliance,* smoking prevalence,* educational campaigns,* cigarette warning labels,* CV risk factors (diet, BMI, etc.),* out-of-hospital deaths*	National database documenting financial coverage of CV treatment, two alternative regression analyses	Flight Attendant Medical Research Institute, Roswell Park Cancer Institute, Institute for Development Research Centre of Canada, Pfizer, U.S. National Cancer Institute	
Cronin et al. (2012)	Retrospective	A, B	Sex, smoking status, ACS type	Admissions trends, demographics and CV risk factors (BMI, cholesterol, etc.), SHS exposure,* smoking prevalence,* other legislation (restricting cigarette pack sizes, etc.),*changes in clinical care*	Time in years and time as a continuous variable, out-of-hospital deaths	Research Institute for a Tobacco Free Society	No suitable comparison population was available

Authors and Year	**Study Type**	**Elements of Study Design**[†]	**Control for Potential Confounders**	**Consideration of Contextual Confounders**[‡*]	**Sensitivity Analyses**	**Funding/Potential Conflict of Interest**	**Comments**
Sargent et al. (2012)	Retrospective	A, B, C	Age, sex, occupation	Economic impacts, cigarette consumption,* incremental ban implementation,* changes in outcome diagnostic criteria* smoking prevalence,* SHS exposure*	Different age group cut-offs	Deutsche Angestellten-Krankenkasse insurance firm, National Institutes of Health	
Kent et al. (2012)	Retrospective	A	Age, PM_{10} air pollution, $PM_{2.5}$ air pollution, temperature, influenza-like-illness rate, influenza case rate	Economic migration, smoking prevalence,* SHS exposure,* indoor air quality,* changes in clinical care*	Grouped v. specific diagnoses	None to declare	Unable to determine SES for further analyses
Hurt et al. (2012)	Retrospective	A, B, C	Age, sex	Smoking prevalence, changes in diagnostic criteria, high cholesterol, diabetes, hypertension, obesity, tobacco control mass media campaigns,* cigarette taxes,* and cigarette sales*		ClearWay Minnesota, National Heart, Lung, and Blood Institute and National Institute on Aging/National Institutes of Health	
Adams et al. (2013)	Retrospective	A, B, C, D	Population growth, cigarette taxes, income, unemployment, linear time trends (in some models), age	Smoking prevalence, prior smoking restrictions	Non-CV deaths, lead and lagged ban effects, two alternative regression analyses, narrower control group, bans in bars	No conflict of interest statement	Assessment period unable to be determined for separate bans due to study design

†Elements of Study Design

A: Clearly defined intervention: smoking ban policy

B: Clearly defined health outcome by specific diagnostic criteria

C: Adjustment for underlying trend in health outcome: hospital admissions and/or deaths

D: Use of comparison population or control diagnoses

‡Potential Contextual Confounders

-Underlying smoking prevalence

-Prior exposure to secondhand smoke (SHS)

-Process of smoking ban implementation: immediate or incremental

-Smoking ban compliance

-Prevalence of non-smoking related risk factors for cardiovascular (CV) or respiratory (Resp.) disease: physical inactivity (CV, Resp.), unhealthy diet (CV, Resp.), overweight and obesity (CV, Resp.), hypertension (CV), hypercholesterolemia (CV), diabetes (CV)

*Indicates contextual confounders discussed, but not directly analysed

Generalisability of Smoking Ban Health Effects

Through the critical appraisal of study fidelity, 6 of the 37 studies were identified as likely to report the most robust findings due to the sufficiently large size of the study population considered, the open declaration of funding sources and/or potential conflicts of interest, thorough adjustment for potential confounding factors, and consideration for contextual confounders that may influence the association between smoking ban policies and health outcomes (Barone-Adesi et al., 2011; Cesaroni et al., 2008; Dove et al., 2010; Mackay et al., 2010a; Pell et al., 2008; Sims et al., 2010). As such, the findings of these studies were used to estimate the potential generalisability of smoking ban policy effects. Each of the six studies assessed the effects of comprehensive smoking bans, and all demonstrated post-ban reductions in cardiovascular morbidity or mortality (n=5) or respiratory morbidity (n=1).

Two of the studies assessed hospital admissions for ACE as determined by ICD-codes (Barone-Adesi et al., 2011; Cesaroni et al., 2008) and one study assessed hospital admissions for ACS as determined by a detectable level of cardiac troponin following emergency admission for chest pain (Pell et al., 2008). These studies demonstrated post-ban reductions of 4-11% roughly 1-2 years post-ban. The greatest benefits were seen in the younger population of Italy, classified as 35-64 years by Cesaroni et al. (2008) and <70 years by Barone-Adesi et al. (2011), but for the population of Scotland, the greatest benefits were seen in the older age groups, classified as men >55 years and women >65 years (Pell et al., 2008). Neither of the Italian studies found differences in effects by sex; however, the Scottish study showed greater benefits in females for both current smokers and non-smokers, but not for former smokers.

Two studies assessed the smoking ban effects specifically for AMI. One year post-ban, reductions of 2.4% (95% CI: -4.1% to -0.7%) in AMI hospital admissions were seen in the English population (Sims et al., 2010), and 2.5 years post-ban, reductions of 7.4% (95% CI: -11.4% to -3.3%) in AMI mortality were seen in the Massachusetts statewide population (Dove et al., 2010). Post-ban benefits in AMI morbidity were seen in persons aged ≥60 years with no effect differences by sex;

however, benefits for persons aged <60 years were only detected in males (Sims et al., 2010). Post-ban benefits in AMI mortality were only detected in females and persons aged ≥75 years (Dove et al., 2010).

Only one of the six most robust studies assessed the smoking ban effects on a respiratory outcome. Mackay et al. (2010a) evaluated the impacts of the Scottish national smoking ban on hospital admissions due to asthma in children aged <15 years. Post-ban, the mean decline in the rate of asthma admissions was 15.1% (95% CI: -17.2% to -12.9%) per year. No differences in effects were detected by age or sex.

Overall, these studies demonstrated that comprehensive smoking ban policies implemented in various countries result in significant post-ban reductions across smoking-related diseases. No specific effect trends were identified when examined by age or sex, which is consistent with the findings observed across all 37 studies in this review.

Smoking Ban Health Effects by SES

As seen in Table 2.4, only three studies considered SES as a risk variable in analyses by assessing for effect modification of smoking ban health effects by SES groups (Barnett et al., 2009; Cesaroni et al., 2008; Mackay et al., 2010a) and two studies controlled for SES as a potential confounding factor (Dove et al., 2010; Shetty et al., 2011). Specifically, a study of the city-wide population of Rome, Italy, assessed the ACE effects in the year following the implementation of the national Italian smoking ban. To examine differences in post-ban effects by SES, census block information was utilised for the following five indicators of deprivation: education, occupation, home ownership, family composition, and nationality (Cesaroni et al., 2008). A composite index including the five SES indicators was then generated through a factor analysis. Post-smoking ban effects demonstrated a clear trend with greater benefits for those of low SES. Particularly, decreases in ACE were significant in the lowest (RR=0.85; 95% CI: 0.77-0.93), second lowest (RR=0.90; 95% CI: 0.81-0.99), and third lowest (RR=0.88; 95% CI: 0.79-0.98) SES quintiles for those of working age (35-64 years), and in the second lowest quintile for ages 65-74 years (RR=0.83; 95% CI: 0.75-0.92).

Table 2.4: Primary Epidemiological Studies Assessing the Health Effects of Smoking Ban Policies by Socioeconomic Status (SES)

Authors, Year, and Location	**Health Outcome**	**Deprivation Indicators**	**Measure of SES**	**Analyses by SES**	**Health Effects by SES Quintiles**
Cesaroni et al. (2008) Rome, Italy	ACE hospital admissions and out-of-hospital deaths in ages 35-84 years	Education Occupation Home ownership Family composition Nationality	Composite index generated by factor analysis	Assessed for effect modification	Ages 35-64 years: 1 (high): RR=0.92 (95% CI: 0.82-1.03) 2: RR=0.90 (95% CI: 0.81-1.01) 3: RR=0.88 (95% CI: 0.79-0.98) 4: RR=0.90 (95% CI: 0.81-0.99) 5 (low): RR=0.85 (95% CI: 0.77-0.93) Ages 65-74 years: 1 (high): RR=0.97 (95% CI: 0.86-1.09) 2: RR=0.90 (95% CI: 0.81-1.01) 3: RR=0.97 (95% CI: 0.87-1.07) 4: RR=0.83 (95% CI: 0.75-0.92) 5 (low): RR=0.94 (95% CI: 0.86-1.04)
Barnett et al. (2009) Christchurch, New Zealand	AMI hospital admissions in all ages	Income Education Employment Home ownership Living space Social support Telephone access Car access	2006 New Zealand Deprivation Index	Assessed for effect modification	Ages 30-54 years: No observed effects for quintiles 1-5 Ages 55-74 years: 1 (high): RR=0.79 (95% CI: 0.59-1.06) 2: RR=0.76 (95% CI: 0.59-0.97) 3: RR=0.84 (95% CI: 0.64-1.12) 4: RR=1.00 (95% CI: 0.79-1.27) 5 (low): RR=0.93 (95% CI: 0.71-1.22) Ages ≥75 years: 1 (high): RR=0.79 (95% CI: 0.62-1.01) 2: RR=0.91 (95% CI: 0.75-1.12) 3: RR=0.88 (95% CI: 0.68-1.15) 4: RR=0.99 (95% CI: 0.83-1.18) 5 (low): RR=0.81 (95% CI: 0.63-1.03)

Authors, Year, and Location	Health Outcome	Deprivation Indicators	Measure of SES	Analyses by SES	Health Effects by SES Quintiles
Mackay et al. (2010a) Scotland	Asthma hospital admissions in ages ≤14 years	Income Education Employment Housing Health Skills and training Geographic access Crime	2006 Scottish Index of Multiple Deprivation	Assessed for effect modification and controlled as confounding factor	Net annual change: 1 (high): -15.6% (95% CI: -21.5% to -9.6%) 2: -14.1% (95% CI: -19.4% to -8.9%) 3: -16.8% (95% CI: -21.8% to -11.8%) 4: -12.5% (95% CI: -17.1% to -7.8%) 5 (low): -16.2% (95% CI: -20.3% to -12.1%)
Dove et al. (2010) Massachusetts, USA	AMI deaths in ages ≥35 years	Median household income Income below federal poverty level Education Employment Disability Foreign born	City/town-specific percentages of deprivation indicators	Controlled as confounding factor	Not reported
Shetty et al. (2011) USA	AMI, asthma, and COPD hospital admissions and AMI deaths	Household income Employment Number of physicians and hospital beds	County-specific percentages of deprivation indicators	Controlled as confounding factor	Not reported

A study of the city-wide population of Christchurch, New Zealand, assessed the effects of the national comprehensive smoking ban on AMI hospital admissions with a follow-up period of two years, utilising home addresses from hospital admissions data to identify the census area unit of each patient to classify SES (Barnett et al., 2009). The ranking of SES quintiles was defined by the 2006 New Zealand Deprivation Index, a combined measure of eight dimensions of deprivation: income, home ownership, social support, employment, educational qualifications, living space, telephone access, and car access (Salmond et al., 2007). SES-stratified data were then used to compare pre- and post-ban admission rates. Overall, the study did not identify consistent trends in post-ban effects by SES. A significant decrease in AMI admissions was observed only for ages 55-74 years in the second highest SES quintile (RR=0.76; 95% CI: 0.59-0.97). For the oldest age group (≥75 years), the decrease in AMI admissions approached significance for both the highest (RR=0.79; 95% CI: 0.62-1.01) and lowest (RR=0.81; 95% CI: 0.63-1.03) quintiles of SES, though the study population size was small and confidence intervals were wide.

To assess the effects of the Scottish national smoking ban on asthma in children ≤14 years, a nation-wide hospital admissions study, with a follow-up period of 3.5 years, utilised the zone of residence for individual patients to classify SES (Mackay et al., 2010a). SES quintiles were based upon the 2006 Scottish Index of Multiple Deprivation, a weighted sum of scores across seven domains: income, employment, health, education, skills and training, housing, geographic access, and crime ("Government of Scotland," 2009). Post-ban decreases in asthma were observed across all SES groups with no significant difference between quintiles (p=0.67) (Mackay et al., 2010a). Though SES was also controlled as a confounding factor in regression analyses, post-adjustment effects were not separately reported.

Two other studies controlled for SES as a confounding factor in regression analyses, but did not assess for effect modification (Dove et al., 2010; Shetty et al., 2011). The first, a study assessing the AMI effects in the 1.5 years following implementation of the state-wide, comprehensive smoking ban in Massachusetts, U.S.A., used the following city and town-specific demographic variables as covariates in regression analyses: percentage unemployed, median household income, percentage with incomes below the federal poverty level, percentage with a college degree, and percentage disabled (Dove et al., 2010). Although the study reported that there was a change in smoking ban rates following adjustment for all confounders in the model, effects relating specifically to SES were not reported.

In a study of the AMI, asthma, and COPD effects following implementation of multiple city and state-wide smoking restrictions throughout the U.S.A., county-level SES indicators such as household income, percentage of the population in the labour force, and the number of physicians and hospital beds were used as covariates to control for SES confounding in regression analyses (Shetty et al., 2011); however, these variables were only used to control for SES in counties from whence data were available and in model specifications when sample size was deemed adequate. Since the study did not clearly report which results were adjusted for SES, determinations regarding specific SES effects were unable to be made.

Also of note, an insurance cohort study assessing AMI and angina hospital admission effects following implementation of partial smoking ban restrictions across German states, used individual-level data to stratify the odds of hospitalisation for AMI and angina by six groups of occupational status (Sargent et al., 2012). When compared to any other occupational group, risk of hospitalisation was greatest in the unemployed for both AMI (OR=1.36; 95% CI: 1.31-1.42) and angina (OR=1.29; 95% CI: 1.25-1.33); however, post-ban health effects were not reported by occupation.

2.5. DISCUSSION

This review found strong evidence for the protective effects of smoking ban policies on cardiovascular morbidity and mortality, with 31 of 35 studies demonstrating post-ban reductions in the overall study population or in specific subgroups. There is increasing evidence that smoking ban policies are also effective in protecting against respiratory morbidity, with 7 of 7 studies demonstrating important post-ban reductions. Insufficient evidence exists to determine smoking ban effects by SES; therefore, policy impacts on health inequalities remain largely unknown.

No clear trend was identified in post-ban effects by age or sex. Although a large number of studies found no differences in effects by these subgroups, further examination of the studies that did detect a difference showed that the greater magnitude of post-ban benefits were almost equivalently divided between younger age groups, older age groups, males, and females. Although the majority of studies that assessed effects by smoking status observed greater post-ban effects in non-smokers, results were not always consistent. Contradictory findings between studies are likely due to the variety of health outcomes evaluated, the underlying prevalence of smoking and exposure to SHS in various population subgroups, the level of enforcement and compliance with the smoking ban policy, and the differing cultural factors between populations that may have affected risk for smoking-related diseases.

The chronological assessment of studies demonstrated the importance of earlier smoking ban research in reporting the general effects of smoking ban policies and generating hypotheses for further research. As smoking ban research methodology has developed over time, with larger study populations, more rigorous analyses, and more thorough adjustment for potential confounding factors, the reported effects have been statistically attenuated, but have also confirmed the importance of smoking ban policies in protecting public health. The discussion of contextual confounders in most studies provided additional strength to findings, going beyond thorough statistical analyses to confirm that factors such as underlying smoking prevalence, SHS exposure, smoking ban compliance, and prevalence of non-smoking related risk factors for the outcomes of interest were also considered and examined. The most robust studies, as identified through the critical appraisal process, confirmed the generalisability of post-ban reductions, in both cardiovascular morbidity/mortality and respiratory morbidity, to other populations. However, post-ban subgroup effects appear to be somewhat population-specific, and therefore should not necessarily be externally generalised to other subgroups beyond the target population.

Although causation cannot be directly determined from observational studies, the evidence of post-smoking ban health effects, as outlined in this review, is even more convincing when the causal inferences of the epidemiologic research are considered with Hill's criteria (Hill, 1965). Biological plausibility and coherence of explanation for the protective health effects of smoking ban policies are supported in that exposure to secondhand smoke can result in morbidity and premature mortality due to cardiovascular and respiratory causes (WHO, 2009, 2011) through enhancement of blood platelet activation and thrombus formation (Glantz & Parmley, 1995) and intensified airway inflammation for asthmatics and persons with COPD (Eisner et al., 2009; Eisner et al., 2005). Comprehensive workplace and public place smoking ban policies, without exclusions for hospitality venues such as restaurants and bars, are effective in minimising exposure to secondhand smoke (Goodman et al., 2007; Repace, 2004) and in reducing active smoking in a population (Fichtenberg & Glantz, 2002). More comprehensive interventions result in greater protective effects (Tan & Glantz, 2012), thereby demonstrating a biological gradient, and temporality is exhibited through the immediately detectable decreases in morbidity and mortality following the implementation of smoking ban policies. Importantly, consistency has been demonstrated across populations and with the use of diverse statistical techniques, including interrupted time-series analyses which are more likely to produce reliable results through the inherent adjustment for underlying trends (Wagner et al. 2002). It is therefore unlikely that there is any unconsidered factor that can account for the protective association between smoking ban policies and health.

Areas for Future Research

In Geoffrey Rose's fundamental paper on population prevention strategies, he underscored the difficulties in assessing situations in which the exposure is widespread and other factors determine varying levels of risk (Rose, 1985). In the instance of a smoking ban policy, when everyone is equally protected by the intervention, other factors may influence varying levels of risk for smoking-related morbidity and mortality. Since smoking status is modified by SES, it is plausible that smoking-related morbidity and mortality would also be modified by SES even under the coverage of a smoking ban policy. Rose maintained that population prevention strategies can result in greater public health benefits than strategies that only narrowly focus on high-risk individuals. The principal reasons are that population-wide strategies can target the underlying causes that lead to disease and can impact a larger number of people, thereby influencing social norms (Rose, 1985).

Since that time, many researchers have entered the debate regarding the most effective methods for implementing interventions and whether to target individuals or populations. Some have presented views suggesting that Rose's population approach to interventions would result in increased health inequalities and, as such, interventions should be specifically tailored to vulnerable populations as a way of addressing these disparities (Frohlich & Potvin, 2008). In contrast, others have argued that there are intrinsic problems in singling out vulnerable populations; for example, a specific cut point would be required for designating those to be targeted for the intervention, and although the definition would be somewhat arbitrary, it could lead to increased marginalisation of those who are already vulnerable (McLaren et al., 2010). The authors additionally claimed that population approaches do not necessarily result in increased inequalities as evidenced by the smoking ban policy effects on smoking prevalence that occur similarly across SES groups; however, no evidence regarding SES differences in post-ban health effects was referenced (McLaren et al., 2010). Although the studies in this review consistently demonstrated the health benefits of smoking ban policies, only 3 of 37 studies assessed effects by SES. As public health interventions should be evidence-based, there is a critical need to determine whether these benefits are experienced equally by all SES groups of the population or whether existing inequalities in health may unintentionally be exacerbated.

There are challenges in assessing smoking ban policy effects by SES. Importantly, individual SES information is not often readily available in mortality or hospital admissions administrative data and therefore must be approximated from other sources. However, as outlined in this review, three studies analysed post-ban effect modification by SES through matching individual records to an area-level SES distribution either derived from a nationally-standardised deprivation index or from a census-specific composite index generated through factor analysis. When a standard deprivation index is already available for the study population, this would be the most applicable measure of SES to employ in analyses, both for expediency and for comparability to other research studies. However, in cases where a standard population-specific index is not available, the best approach would be to identify from relevant census data the area-level indicators appropriate for estimating SES in the population and jointly analyse them in a factor analysis to create a composite index.

Although there are disadvantages to this second approach, these can be surmounted as outlined below. First, information on income is often not included in census data; nonetheless, other indicators, such as housing tenure or motor vehicle access, can serve as proxies for material resources (Davey Smith & Egger, 1992; Davies et al., 1997; Macintyre et al., 1998). Second, factor analysis has been criticised for yielding an infinite number of mathematically comparable results; however, the most appropriate solution can be determined through a rigorous methodology (Kline, 1994) and with a strong, contextual understanding of the indicators most appropriate for approximating SES in the specific study population. There is also an extensive body of literature describing social epidemiologic methods that can aid in identifying appropriate SES indicators (Diez-Roux et al., 2001; Krieger, 1992; Krieger et al., 2003; Krieger et al., 1997; Minardi et al., 2011; Reijneveld et al., 2000).

A key benefit of this approach is that, through the provision of transparent explanations of methodological procedures and by explaining rationales in decision-making, researchers can generate a reproducible composite SES index not only specific to the study purpose, but also for use in additional studies of health inequalities. Regardless of the techniques employed, there is an urgent need for strong epidemiological studies to provide the necessary evidence of post-ban health effects by SES to identify health inequalities and to inform public health policy.

Sufficient evidence currently exists in support of the protective cardiovascular effects of smoking ban policies. Therefore, research foci should expand to include the assessment of post-ban cerebrovascular effects, specifically due to stroke mortality which has not yet been assessed in any studies, along with post-ban respiratory effects for which evidence is limited. The immediate post-ban reductions in asthma morbidity for children indicate that the benefits of comprehensive smoking bans may be experienced for all age groups, even though previous studies have primarily focussed upon establishing health improvements for adults, most often with cardiovascular outcomes. Even less evidence is available regarding post-ban changes in COPD; as a result, the implications are more difficult to interpret. Secondhand smoke exposure in non-smokers is associated with increased prevalence of COPD (Jordan et al., 2011; Yin et al., 2007) and with increased exacerbations of COPD resulting in the need for hospital-based care (Eisner et al., 2009). Therefore, it is plausible that the implementation of smoking ban policies would result in decreased COPD exacerbations. More evidence would aid in elucidating this relationship.

Only two studies of smoking ban effects were conducted in developing countries (Ferrante et al., 2012; Sebrié et al., 2012). Due to targeted marketing by tobacco companies, particularly to women and children (McNabola et al., 2006; WHO, 2008), tobacco use continues to increase in developing countries. Smoking ban policies could be a driving force in reversing the trend of increased morbidity and mortality that will inevitably follow in the absence of protective legislation. More research is needed in developing countries to provide the evidence base for policymakers to advocate for smoking ban policies. As public health problems are identified and addressed within industrialized nations, it is important to ensure that the same problems are not merely displaced to other, less developed areas of the world (Pearce, 1996).

Limitations and Strengths

Due to the purposive exclusion of unpublished literature and of studies with self-reported outcomes, this review was not exhaustive of all smoking ban research. The 37 reviewed studies were observational and demonstrated considerable heterogeneity in intervention type, study population, selection of outcome diagnostic criteria, and statistical methods for assessment of effects; therefore, it was important to engage a narrative synthesis to permit consideration of additional confounding factors that may have influenced the association between the intervention and outcome. Elements of narrative synthesis are, to a certain extent, subjective. However, when compared to meta-analytic techniques, narrative synthesis allows for a more thorough examination of contextual factors and implications for future research (Rodgers et al., 2009).

As recommended by Egger et al. (2001) for a review of observational studies, this review was conducted based upon a study protocol written in advance, the database searches were conducted systematically, and the selection of primary studies was objective and reproducible. This review was the first to consider the SES impacts of smoking ban policies with outcomes of mortality and hospital-diagnosed morbidity. The chronological assessment of primary studies demonstrated the development of methods over time and the narrative synthesis aided in identifying specific areas in which future research is needed. Specifically, this review has called attention to issues of major public health importance by providing corroborative evidence that smoking ban policies are effective measures for reducing cardiovascular morbidity and mortality and highlighting the need for research into the smoking ban effects on stroke and respiratory mortality and assessment of health effects by SES.

2.6. CONCLUSION

Several rigorous epidemiologic research studies conducted across continents have provided consistent evidence that smoking ban policies yield important public health benefits. However, there is insufficient evidence to determine the distribution of health benefits across socioeconomic groups. To achieve the public health aim of reducing health inequalities, future epidemiological research studies of smoking ban effects should examine outcomes by SES.

2.7. UPDATE: Newly Published Studies

Since the time this review was conducted, ten newly published studies were identified through electronic database notifications, including a study arising from the next chapter of this thesis. Two of the ten studies were published in late 2012; however, due to the lag of time between the original article publication date and the date when article access became available through the databases, electronic notification was not received until after January 2013, when this review was finalised. Each of the newly published studies has been summarised in Table 2.5.

Brief Overview of Studies

Three studies examined effects due to both cardiovascular and respiratory causes, but the most common assessment was for post-ban cardiovascular effects alone (n=5), with two studies examining only post-ban respiratory effects. As in the full review of 37 studies, the most predominant outcome for newly published studies was hospital admissions due to cardiovascular causes, followed by hospital admissions due to respiratory causes, and cardiovascular mortality. Two studies assessed post-ban changes in stroke mortality (Mackay et al., 2013; Stallings-Smith et al., 2013) and only one study assessed post-changes in respiratory mortality (Stallings-Smith et al., 2013). One of the ten studies was an update of a previously reviewed study (Sebrié et al., 2012) with an extended analysis of a longer post-ban follow-up period (Sebrié et al., 2013). Most of the studies (80%) assessed the health effects of comprehensive smoking ban policies, with two studies assessing post-ban effects of partial smoking legislation. Again consistent with the previous review of 37 studies, the majority of newly published studies evaluated populations in Europe (n=5) or North America (n=4), with only one study examining a population in South America (Sebrié et al., 2013).

Specific analytical adjustments for potential confounding factors were made most frequently for season (n=7), age (n=6) and sex (n=6). Discussion of additional contextual factors that may also act as potential confounders was included in 90% of studies, particularly relating to demographic changes, population exposure to SHS, smoking prevalence, changes in diagnostic coding schemes, ban compliance, and changes in potential risk factors for cardiovascular and respiratory disease such as obesity. Only one study did not include a competing interest/funding statement, a peer-reviewed brief report published in the Centers for Disease Control and Prevention (CDC) journal *Preventing Chronic Disease*; however, the correspondence information listed for the authors indicated academic affiliation with health research centres (Head et al., 2012).

Table 2.5: Newly Published Studies: Update of Chronological Summary of Primary Epidemiological Studies Assessing the Cardiovascular and Respiratory Effects of Smoking Ban Policies

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Barr et al. (2012) 387 Counties in Illinois, Ohio, Minnesota, New York, Washington, New Jersey, Arizona, Massachusetts, and Delaware, USA	County-wide comprehensive smoking bans including hospitality venues: Jan. 2000-Dec. 2007	~64,000 AMI admissions in Medicare enrollees aged ≥65 years 1999-2008	Random-effects Poisson regression adjusted for linear and non-linear admission trends, season, age group, and sex	Linear trend: 4.93% decrease (95% CI: -6.26% to -3.59%) Non-linear trend: 0.62% decrease (95% CI: -2.45% to 3.79%)	Not reported

Authors, Year, and Location	**Smoking Ban Policy and Implementation Date**	**Study Population and Assessment Period**	**Analytical Method and Adjustments for Potential Confounders**	**Overall Post-Ban Health Effects**	**Subgroup Post-Ban Health Effects***
Head et al. (2012) Beaumont, Texas, USA	City-wide comprehensive smoking ban including hospitality venues: 1 Aug. 2006	All-cause, AMI, stroke, transient ischemic attack, COPD, and asthma hospital discharges in Beaumont (ban enforced; n=77,849), Tyler (no ban enforced; n=47,319), and all of Texas (mixed policies; n=11.5 million) Jul. 2004-Jun. 2008	Rate comparison analysis from two years pre-ban to two years post-ban stratifying by black/white race	Beaumont: AMI: Rate Ratio (RR)=0.74 (95% CI: 0.65-0.85) Stroke: RR=0.71 (95% CI: 0.62-0.82) Transient Ischemic Attack: RR=0.92 (95% CI: 0.78-1.09) COPD: RR=0.88 (95% CI: 0.78-1.00) Asthma: RR=0.98 (95% CI: 0.85-1.14) Tyler: No effects except for Stroke: RR=0.73 (95% CI: 0.62-0.86) All of Texas: Attenuated effects detected for all outcomes	AMI: Non-Hispanic Blacks: RR=0.68 (95% CI: 0.55-0.85) Non-Hispanic Whites: RR=0.63 (95% CI: 0.52-0.75) Stroke: Non-Hispanic Blacks: RR=0.75 (95% CI: 0.62-0.91) Non-Hispanic Whites: RR=0.53 (95% CI: 0.43-0.65) COPD: Non-Hispanic Blacks: RR=1.04 (95% CI: 0.85-1.27) Non-Hispanic Whites: RR=0.64 (95% CI: 0.54-0.75)
Millett et al. (2013) England	National comprehensive smoking ban including hospitality venues: 1 Jul. 2007	217,381 asthma hospital admissions in ages ≤14 years Apr. 2002-Nov. 2010	Interrupted time-series negative binomial regression adjusting for linear time trend, season, quintile of deprivation, urban/ rural status, region, age group, and sex	Immediate change: RR=0.91 (95% CI: 0.89-0.94) Trend change: RR=0.97 (95% CI: 0.96-0.98)	Immediate change: Males: RR=0.90 (95% CI: 0.87-0.93) Females: RR=0.93 (95% CI: 0.90-0.96)

Authors, Year, and Location	Smoking Ban Policy and Implementation Date	Study Population and Assessment Period	Analytical Method and Adjustments for Potential Confounders	Overall Post-Ban Health Effects	Subgroup Post-Ban Health Effects*
Aguero et al. (2013) Girona Province, Spain	National partial smoking ban excluding bars, restaurants, and night clubs: 1 Jan. 2006	AMI population incidence (n=3,703), hospital admissions (n=3,011), mortality (891), and 28-day case fatality (891) in ages 35-74 years 2002-2008	Negative binomial regression adjusting for underlying linear trend and season and stratifying by age, sex, and smoking status	Incidence: Relative Risk=0.89 (95% CI: 0.81-0.97) Hospital admissions: Relative Risk=0.89 (95% CI: 0.81-0.98) Mortality: Relative Risk=0.82 (95% CI: 0.71-0.94) 28-day Case Fatality: Relative Risk=0.93 (95% CI: 0.81-1.06)	Incidence: Males: Relative Risk=0.93 (95% CI: 0.86-0.99) Females: Relative Risk=0.82 (95% CI: 0.70-0.96) Smokers: Relative Risk=0.94 (95% CI: 0.83-1.06) Non-smokers: Relative Risk=0.85 (95% CI: 0.76-0.95)
Gaudreau et al. (2013) Prince Edward Island, Canada	Province-wide partial smoking ban with exemptions for designated smoking rooms: 1 Jun. 2003 Amended to include school grounds: 1 Jul. 2006	Hospital admissions (# not reported) for AMI, angina, stroke, asthma, COPD, and three control conditions Apr. 1995-Dec. 2008	ARIMA time-series analysis adjusting for underlying admission trends and stratifying by age group and sex	Mean change in admissions per 100,000 person-months: AMI: -5.92 cases (95% CI: -11.44 to -0.39) Angina: -3.39 cases (-19.63 to 12.85) Stroke: -3.04 cases (-13.14 to 7.06) Pediatric Asthma: 1.11 cases (0.63 to 1.95) COPD: -6.66 cases (-23.97 to 10.64)	Mean change in AMI admissions per 100,000 person-months: Males: -7.70 cases (-17.87 to 2.46) Females: -1.54 cases (-10.27 to 7.18) Ages 35-64 years: -3.01 cases (-7.26 to 1.23) Ages 65-104 years: -9.60 cases (-38.52 to 19.32)
Johnson and Beal (2013) Grand Forks, North Dakota, USA	City-wide extension of partial smoking ban to include bars and other previously exempted venues: 15 Aug. 2010	146 AMI and ACS hospital admissions Apr. 2010-Dec. 2010	Chi-square comparison analysis of rates adjusting for season by study design	30.6% decrease (p<0.023)	Not reported

Authors, Year, and Location	Smoking Ban Policy and Implementation Date	Study Population and Assessment Period	Analytical Method and Adjustments for Potential Confounders	Overall Post-Ban Health Effects	Subgroup Post-Ban Health Effects*
Sims et al. (2013) England	National comprehensive smoking ban including hospitality venues: 1 Jul. 2007	502,000 asthma hospital admissions in ages ≥16 years Apr. 1997-Dec. 2010	Poisson generalised additive model adjusting for non-linear region-specific time trend, season, temperature, influenza epidemics, number of days/month, and variation in population size	4.9% decrease (95% CI: -0.6% to -9.0%)	Examples of region-specific effects: London: 7.6% decrease (*p*<0.001) South East: 26.7% decrease (*p*<0.001) North West: 5.1% increase (*p*<0.02)
Stallings-Smith et al. (2013) Republic of Ireland	National comprehensive smoking ban including hospitality venues: 29 Mar. 2004	215,878 all-cause, non-trauma deaths, including deaths due to IHD (n=44,993) stroke (n=17,930), and COPD (n=11,117) in ages ≥35 years 2000-2007	Interrupted time-series Poisson regression analysis adjusting for time trend, season, influenza epidemics, smoking prevalence, age, and sex	Immediate Change: IHD: RR=0.74 (95% CI: 0.63-0.88) Stroke: RR=0.68 (95% CI: 0.54-0.85) COPD: RR=0.62 (95% CI: 0.46-0.83)	Immediate Change in IHD: Males: RR=0.71 (95% CI: 0.58-0.86) Females: RR=0.79 (95% CI: 0.64-0.97) Ages 35-64 years: RR=0.74 (95% CI: 0.53-1.02) Ages 65-84 years: RR=0.74 (95% CI: 0.61-0.89) Ages ≥85 years: RR=0.78 (95% CI: 0.62-0.99)

Authors, Year, and Location	Smoking Ban Policy and Implementation Date	Study Population and Assessment Period	Analytical Method and Adjustments for Potential Confounders	Overall Post-Ban Health Effects	Subgroup Post-Ban Health Effects*
Mackay et al. (2013) Scotland	National comprehensive smoking ban including hospitality venues: 26 Mar. 2006	85,662 hospital admissions and pre-hospital stroke deaths in all ages 2000-2010	Negative binomial regression adjusting for underlying trend, month, year, deprivation quintile, urban/rural classification, age group, and sex	Immediate change: -6.65% (95% CI: -10.22% to -2.95%) Trend change: -0.23% (95% CI: -1.49% to 1.06%)	Immediate change: Males: -6.81% (95% CI: -11.82% to -1.57%) Females: -6.51% (95% CI: -11.31% to -1.45%) Ages <60 years: -7.13% (95% CI: -10.87% to -3.24%) Ages ≥60 years: -4.76% (95% CI: -13.84% to 5.29%)
Sebrié et al. (2013) Uruguay	National comprehensive smoking ban including hospitality venues: 1 Mar. 2006	11,135 AMI hospital admissions in ages ≥20 years Mar. 2004-Feb. 2010	Multiple linear and negative binomial regression analyses adjusting for underlying trend and season	Multiple linear: 31 admissions per month decrease (95% CI: -50 to -12) (*p*=0.002) Negative binomial: Incidence RR=0.83 (95% CI: 0.74-0.92)	Not reported

Nine out of ten studies demonstrated significant post-ban reductions in cardiovascular and/or respiratory outcomes. The other study, which assessed AMI hospital admissions in Medicare enrollees aged ≥65 years in 387 counties of the USA, observed a post-ban decrease in AMI admissions with the use of a linear time trend in regression models; however, no effect was observed with the use of a non-linear time trend (Barr et al., 2012). The authors hypothesised that a county-wide smoking ban may have had only limited influence on the personal SHS exposure of most Medicare enrollees due to the smaller time spent in workplaces, bars, and restaurants as compared to younger age groups.

As shown in Table 2.6, only two studies examined post-ban effects by SES, both of which employed nationally-standardised indices of multiple deprivation for stratified analyses (Mackay et al., 2013; Millett et al., 2013). The first, a study assessing the effects of the national English comprehensive smoking ban on asthma admissions in ages ≤14 years, utilised home addresses from hospital admissions data to classify neighbourhood-level SES for each patient according to the 2007 English Index of Multiple Deprivation (Millett et al., 2013). Post-ban decreases in asthma were observed across SES groups with overlapping confidence intervals for all SES quintiles. These findings were consistent with that of a similar Scottish study of asthma hospital admissions in children, which detected no difference in post-ban effects across SES quintiles (Mackay et al., 2010a).

The second study assessed the effects of the national Scottish comprehensive smoking ban on stroke admissions and pre-hospital deaths in all ages (Mackay et al., 2013). Postcodes of residence were used to classify area-level SES as defined by the Scottish Index of Multiple Deprivation. The strongest post-ban reductions in stroke were detected in the most affluent quintile, with no effects observed in the most deprived quintile. These findings indicate that the national smoking ban potentially widened the inequalities gap in stroke between the least and most deprived of Scotland.

Table 2.6: Newly Published Studies: Update of Primary Epidemiological Studies Assessing the Health Effects of Smoking Ban Policies by Socioeconomic Status (SES)

Authors, Year, and Location	**Health Outcome**	**Deprivation Indicators**	**Measure of SES**	**Analyses by SES**	**Health Effects by SES Quintiles**
Millett et al. (2013) England	Asthma hospital admissions in ages ≤14 years	Income Employment Health and Disability Education Skills and training Housing Living Environment Crime	2007 English Index of Multiple Deprivation	Assessed for effect modification and controlled as confounding factor	1 (high): RR=0.94 (95% CI: 0.89-0.99) 2: RR=0.91 (95% CI: 0.87-0.96) 3: RR=0.86 (95% CI: 0.82-0.90) 4: RR=0.92 (95% CI: 0.87-0.96) 5 (low): RR=0.93 (95% CI: 0.89-0.98)
Mackay et al. (2013) Scotland	Stroke hospital admissions and out-of-hospital deaths	Income Education Employment Housing Health Skills and training Geographic access Crime	Scottish Index of Multiple Deprivation (year not reported)	Assessed for effect modification and controlled as confounding factor	Net annual change: 1 (high): -9.68% (95% CI: -14.61% to -4.47%) 2: -4.63% (95% CI: -8.09% to -1.03%) 3: -11.82% (95% CI: -22.56% to 0.41%) 4: -2.20% (95% CI: -9.44% to -5.62%) 5 (low): -2.47% (95% CI: -5.55% to 0.71%)

Consistent with the findings of the previous review of 37 studies, ten newly published studies have also highlighted that more evidence of smoking ban health effects is needed in developing countries, and for industrialised countries, evidence is needed regarding smoking ban effects on respiratory mortality and differences in effects by SES. Through consistency and reproducibility across studies, clear trends can be identified to further aid in the development of public health policy.

CHAPTER 3: Reductions in Cardiovascular, Cerebrovascular, and Respiratory Mortality Following the National Irish Smoking Ban: Interrupted Time-Series Analysis

3.1. ABSTRACT

Background: Previous studies have shown decreases in cardiovascular mortality following the implementation of comprehensive smoking bans. It is not known whether cerebrovascular or respiratory mortality decreases post-ban. On March 29, 2004, the Republic of Ireland became the first country in the world to implement a national workplace smoking ban. The aim of this study was to assess the effect of this policy on all-cause and cause-specific, non-trauma mortality.

Methods: A time-series epidemiologic assessment was conducted, utilising Poisson regression to examine weekly age and gender-standardised rates for 215,878 non-trauma deaths in the Irish population, ages ≥35 years. The study period was from January 1, 2000, to December 31, 2007, with a post-ban follow-up of 3.75 years. All models were adjusted for time trend, season, influenza, and smoking prevalence.

Results: Following ban implementation, an immediate 13% decrease in all-cause mortality (RR: 0.87; 95% CI: 0.76-0.99), a 26% reduction in ischemic heart disease (IHD) (RR: 0.74; 95% CI: 0.63-0.88), a 32% reduction in stroke (RR: 0.68; 95% CI: 0.54-0.85), and a 38% reduction in chronic obstructive pulmonary disease (COPD) (RR: 0.62; 95% CI: 0.46-0.83) mortality was observed. Post-ban reductions in IHD, stroke, and COPD mortalities were seen in ages ≥65 years, but not in ages 35-64 years. COPD mortality reductions were found only in females (RR: 0.47; 95% CI: 0.32-0.70). Post-ban annual trend reductions were not detected for any smoking-related causes of death. Unadjusted estimates indicate that 3,726 (95% CI: 2,305-4,629) smoking-related deaths were likely prevented post-ban. Mortality decreases were primarily due to reductions in passive smoking.

Conclusions: The national Irish smoking ban was associated with immediate reductions in early mortality. Importantly, post-ban risk differences did not change with a longer follow-up period. This

study corroborates previous evidence for cardiovascular causes, and is the first to demonstrate reductions in cerebrovascular and respiratory causes.

3.2. INTRODUCTION

Exposure to secondhand smoke increases the risk of morbidity and premature mortality due to cardiovascular (WHO, 2011), cerebrovascular (Oono et al., 2011), and respiratory (WHO, 2011) causes. On March 29, 2004, the Republic of Ireland became the first country in the world to implement a national workplace smoking ban. The legislation was comprehensive, banning smoking in workplaces including restaurants, bars, and pubs.

Following the implementation of the Irish national smoking ban, studies conducted in pubs and bars demonstrated reductions in particulate concentrations (Goodman et al., 2007), reductions in worker-reported exposure to secondhand smoke (Allwright et al., 2005; Mulcahy et al., 2005), and related improvements in worker pulmonary function (Goodman et al., 2007) and self-reported respiratory symptoms (Allwright et al., 2005). More recent Irish studies have shown post-ban reductions in hospital admissions due to acute coronary syndromes (Cronin et al., 2012; Kent et al., 2012) and acute pulmonary disease (Kent et al., 2012). Epidemiological studies of the effects of comprehensive smoking bans in other countries have demonstrated reductions in mortality due to cardiovascular causes (Cesaroni et al., 2008; Dove et al., 2010; Pell et al., 2008; Villalbi et al., 2011) and hospital admissions due to cardiovascular (Barnett et al., 2009; Barone-Adesi et al., 2011; Bartecchi et al., 2006; Herman & Walsh, 2011; Juster et al., 2007; Naiman et al., 2010; Pell et al., 2008; Sims et al., 2010; Vasselli et al., 2008; Villalbi et al., 2009), cerebrovascular (Herman & Walsh, 2011; Naiman et al., 2010), and respiratory causes (Herman & Walsh, 2011; Mackay et al., 2010a; Naiman et al., 2010). Most of the studies analysed a post-ban follow-up period of 2.5 years or less (Barnett et al., 2009; Barone-Adesi et al., 2011; Bartecchi et al., 2006; Cesaroni et al., 2008; Dove et al., 2010; Herman & Walsh, 2011; Juster et al., 2007; Naiman et al., 2010; Pell et al., 2008; Sims et al., 2010; Vasselli et al., 2008; Villalbi et al., 2009; Villalbi et al., 2011), with only one study analysing a post-ban time period of 3.5 years (Mackay et al., 2010a). None of the studies analysed post-ban mortality effects in cerebrovascular or respiratory causes. The aim of this study was to assess the effect of the national smoking ban on all-cause and cause-specific, non-trauma mortality in the Republic of Ireland for the years 2000-2007.

3.3 METHODS

Data for the Republic of Ireland

National mortality data from January 1, 2000, to December 31, 2007, were obtained from the Central Statistics Office (CSO) Ireland. From 2000-2006, mortality data were coded according to the *International Classification of Diseases, 9th Revision* (ICD-9); ICD-10 codes were implemented in 2007. Primary causes of death selected for analyses included all-cause, non-trauma mortality (ICD-9 codes 001-799/ICD-10 codes A00-R99), smoking-related mortality including all cardiovascular diseases (390-429/I01-I52), ischemic heart disease (IHD) (410-414, 429.2/I20-I25), acute myocardial infarction (AMI) (410/I21), stroke (430-438/I60-I69), all respiratory diseases (460-519/J0-J99), and chronic obstructive pulmonary disease (COPD) (490-492, 494-496/J40-J44, J47). Non-smoking related mortality (001-389, 440-459, 520-799/A00-H95, I26-I52, K00-R99) was included as a control. Mortality records with missing information for cause of death, age, or sex were excluded from analyses (0.52% of records).

Age and gender-specific population estimates for the census years 2002 and 2006 were obtained from the CSO Ireland (CSO, 2007).

Statistical Analyses

Poisson regression with interrupted time-series analysis was used to calculate weekly mortality rates. The average of age and gender-specific population figures for census years 2002 and 2006 was included as an offset in the models. Time was defined as a continuous variable from week 1 of 2000 to week 51 of 2007 and was included in the model to capture long-term trends in mortality rates over time. Week 0 of 2000 and week 52 of 2007 were excluded from analyses as some days fell in other calendar years.

An indicator variable was used to define the smoking ban, with a value of zero given to the weeks before ban implementation and a value of one given to the week of ban implementation (beginning March 28, 2004) and all following weeks. An interaction term between the smoking ban and time was defined to estimate the monotonic change in the post-ban period. The analysis was restricted to mortality events in age groups ≥35 years to reflect the population at risk for smoking-related mortality.

To test for non-linearity of the time trend, time was re-defined as a zero-degree spline variable, the most applicable spline transformation for modelling a continuous variable with a discrete step function (SAS, 2012). The goodness of fit for the linear versus non-linear models was compared using the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). As Table 3.1 demonstrates, the linear assumptions of interrupted time-series analysis were found to be appropriate.

An attribute of time-series data is that adjacent observations in time are typically correlated with one another, a phenomenon known as autocorrelation (Gottman, 1981). The Durbin-Watson statistic detects whether autocorrelation is present and in what direction the observations are correlated (SAS, 2011a). Generalised Durbin-Watson statistics for each cause of death indicated first-order autocorrelation for the mortality data (Table 3.2). If uncorrected, the model would erroneously underestimate or overestimate the standard errors of the coefficients as a result of positive or negative autocorrelation, respectively (Velicer & Colby, 2005). To account for this, terms specifying a first-order autoregressive structure were applied to all models, resulting in observations that were exponentially less correlated as the distance, or time, between observations increased (Kincaid, 2005).

Table 3.1: Goodness of Fit Statistics* Comparing Linear versus Non-Linear Time Trends in Mortality, Ages ≥35 years, Republic of Ireland, 2000-2007

	Linear Time Trend		**Non-Linear Time Trend**	
Cause of Death	**AIC**	**BIC**	**AIC**	**BIC**
All Mortality	486005.7	486060.9	486037.9	486093.1
All Cardiovascular	175434.1	175489.2	175486.1	175541.2
Ischemic Heart Disease	126169.7	126224.8	126222.9	126278.0
Acute Myocardial Infarction	80690.97	80746.11	80723.02	80778.16
Stroke	68123.27	68178.41	68146.51	68201.65
All Respiratory	125480.5	125535.6	125535.8	125590.9
COPD	44674.85	44729.99	44690.78	44745.92

*Smaller values indicate a better fit

Table 3.2: Durbin-Watson Statistics Representing First-Order Autocorrelation of the Weekly Mortality Time-Series in Ages ≥35 years, Republic of Ireland, 2000-2007

Cause of Death	**Durbin-Watson Statistic**	**p-value**
All Mortality	1.7779	<.0001
All Cardiovascular	2.0649	0.0698
Ischemic Heart Disease	2.2564	<.0001
Acute Myocardial Infarction	2.0854	0.0230
Stroke	1.7469	<.0001
All Respiratory	1.5662	<.0001
COPD	1.6580	<.0001

In 2007, the change in coding scheme from ICD-9 to ICD-10 resulted in a 43% decrease in pneumonia/influenza mortality compared to 2006 (Table 3.3). Since roughly 49% of all respiratory mortality was comprised of pneumonia/influenza over the 2000-2006 study period, the large decrease in 2007 affected data reliability for this category. Therefore, 2007 data were excluded from analyses of all respiratory mortality. No other causes of death were affected by the coding change.

Table 3.3: Age and Gender-Standardised All-Cause (Non-Trauma)* and Cause-Specific Mortality Rates per 10,000 Population† for Ages ≥35 years in the Republic of Ireland, 2000-2007‡

Cause of Death	ICD-9 Codes	ICD-10 Codes	Year							
			2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Total Mortality	001-799	A00-R99	148.86	143.15	140.57	138.42	136.19	133.39	141.65	138.89
All Cardiovascular	390-429	I01-I52	45.95	43.16	42.49	40.19	39.50	37.51	37.56	37.45
Ischemic Heart Disease	410-414, 429.2	I20-I25	33.78	31.72	31.41	28.64	28.14	26.35	25.97	27.66
Acute Myocardial Infarction	410	I21	20.60	19.35	18.54	16.32	16.09	14.78	15.06	14.18
Stroke	430-438	I60-I69	14.00	13.28	12.31	11.72	10.83	10.41	9.94	10.63
All Respiratory	460-519	J0-J99	24.79	22.92	22.27	22.86	20.98	20.77	21.01	17.05
Pneumonia/Influenza	480-487	J09-J18	12.83	11.54	11.25	11.35	10.15	9.97	10.16	5.79
COPD	490-492, 494-496	J40-J44, J47	8.14	7.43	7.21	7.32	6.95	6.73	6.57	7.39
Non-Smoking Related Mortality	001-389, 440-459, 520-799	A00-H95, I26-I52, K00-R99	64.13	63.79	63.50	63.65	64.89	64.70	73.13	73.75

*Excluded injuries: ICD-9 codes 800-999 and ICD-10 codes S00-Z99
†Age and gender-standardised according to average census population figures for 2002 and 2006
‡ICD-9 codes were used from 2000-2006; ICD-10 codes were implemented in 2007

To detect any differences between short-term and long-term post-ban mortality effects, an additional indicator variable was included in final models. Values of one were given for the week of ban implementation and the subsequent weeks up to one, three, six, or twelve months post-ban, with all other weeks denoted by a value of zero.

For further validation that the final models were detecting true ban effects, three additional models were refitted with false smoking ban implementation dates set at six months, one year, and two years pre-ban.

A peak in observed mortality was detected during the winter of 1999-2000; therefore, two additional models were tested to determine whether the full inclusion (beginning December 1999) or full exclusion (beginning April 2000) of the winter season influenced model results.

To determine the modifying effects of age and gender on the smoking ban-mortality association, analyses were stratified for ages 35-64 years, ages 65-84 years, and ages ≥85 years, males, and females. Due to the small number of events in each subcategory, it was not possible to stratify by age and gender simultaneously.

Potential Confounders

Adjustments were made for temporal changes in season, influenza activity, and national smoking prevalence. Seasonal patterns in mortality due to cardiovascular (Ornato et al., 1996; Pell & Cobbe, 1999) and respiratory causes (Hansell et al., 2003) have been well-documented and have been attributed to environmental factors such as fluctuations in temperature and the resulting influence on vulnerable populations, as well as fluctuations in individual lifestyle habits such as diet and physical activity levels (Pell & Cobbe, 1999). To control for season as a potential confounder, it was designated based upon calendar weeks with winter defined as December-February, spring as March-May, summer as June-August, and autumn as September-November. Seasonal adjustment with annual and semi-annual sine and cosine terms was also tested.

Infection with influenza can also trigger cardiovascular and respiratory mortality (Warren-Gash et al., 2009; Wesseling, 2007). Furthermore, laboratory experiments in mice have shown that exposure to cigarette smoke can enhance the effects of influenza, causing potentially fatal overactive immune responses (Kang et al., 2008); thus, high circulating levels of influenza may act as a potential confounder to the mortality effects of a smoking ban intervention. Weekly surveillance data for influenza-like illnesses (ILI) were available from the Irish Health Protection Surveillance Centre (HPSC, 2011b) for the influenza seasons (October-May) of 2000-2001 to 2007-2008. ILI activity for the influenza season of 1999-2000 was approximated using published data from the European Influenza Surveillance Scheme (Mantey & Mosnier, 2000). Periods of high ILI activity were defined as weeks when the reported rate of ILI was ≥60/100,000, roughly twice the background rate of ILIs for the Republic of Ireland.

Since changes in population smoking prevalence could impact smoking-related mortality, it was an important factor to consider as a potential confounder. Monthly smoking prevalence data from a nationally representative computer-assisted telephone survey of 1,000 persons per month, ages ≥15 years, were obtained from the Ireland Office of Tobacco Control (OTC) (OTC, 2012). Data were available for the months of July 2002-December 2007. A linear regression fitted to OTC data was used to approximate smoking prevalence for 2000-2001. Annual averages were calculated to adjust for smoking prevalence in all models.

Model adjustments for the following potential confounders were also considered: holidays, weather, and air pollution. The overconsumption of unhealthy foods, decreased activity levels, and increased financial and emotional stress around the Christmas and New Year holidays have all been cited as contributing to increased cardiovascular mortality (Kloner, 2004; Kloner et al., 1999). An indicator variable, designated with a value of one for the first and last weeks of each year and a value of zero otherwise, was tested as a covariate to account for the possible mortality effects of the end-of-year holidays. However, the inclusion of this variable did not appreciably influence model results. Therefore, to preserve model efficiency, it was excluded from further analyses.

Adjustments for weather and air pollution were not possible due to insufficient information. The assignment of regional weekly mean temperatures to individual mortality events resulted in several weeks of time in which no deaths occurred, thereby preventing further analyses. Similarly, air pollution data were only available for roughly 15% of the study population, which did not allow for adequate statistical power to detect an effect.

Presentation of Results

The Poisson model equation estimating weekly mortality rates was expressed as follows:

$$Log(E(Y)) = \beta_0 + \beta_1 TimeW + \beta_2 BAN + \beta_3 (TimeW * BAN) + \beta_k (SP, I, Season) + e \qquad (1)$$

where *Y* denotes the response (weekly mortality), β_0 is the model intercept, β_1 is the model coefficient for the weekly time trend variable, β_2 is the coefficient of the indicator variable for smoking ban policy implementation, β_3 is the coefficient of the interaction between the indicator variable for *BAN* and the weekly time trend, β_k denotes the effects for a set of covariates of interest (*smoking prevalence-SP, influenza-I,* and *Season*), and *e* is the model error term.

In the pre-ban period (Figure 3.1), *Ban* = 0, and the model takes the form:

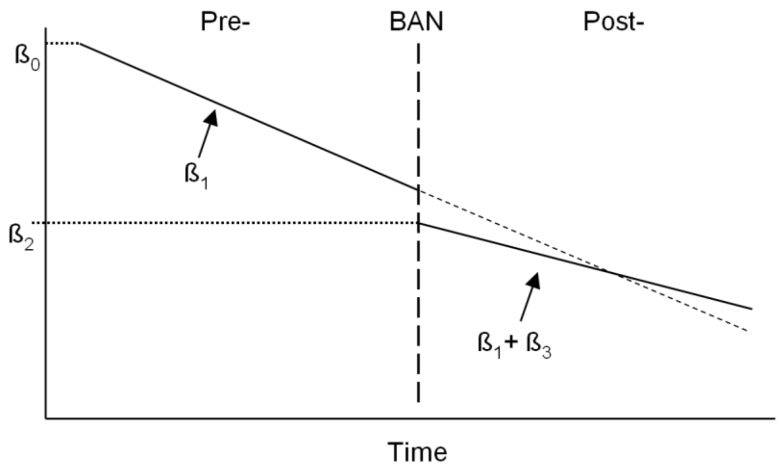
$$Log(E(Y)) = \beta_0 + \beta_1 TimeW + \beta_k (SP, I, Season) + e \qquad (2)$$

In the post-ban period, Ban = 1, thus the model takes the form:

$$Log(E(Y)) = (\beta_0 + \beta_2) + (\beta_1 + \beta_3) TimeW + \beta_k (SP, I, Season) + e \qquad (3)$$

where β_2 is the change in the log rate ratio for the immediate effect of the smoking ban and ($\beta_1 + \beta_3$) is the post-ban rate of change in mortality, with β_3 representing the change in slope after the ban.

Figure 3.1: Interpretation of Interrupted Time-Series Model Results*†
*The Y axis represents weekly mortality, the X axis represents Time, and the bold line represents the monotonic mortality change pre- and post-ban.
†The vertical interrupted line represents the time of the smoking ban policy implementation.



For results presentation, rate ratios (RR) were calculated for the immediate effect coefficients as $[\exp(\beta_2)]$, and weekly trend effect coefficients were converted to annual change with $[\exp(\beta_1 + \beta_3)*52]$. The 95% confidence intervals (CI) for the annual trend effect accounted for the overall variance of the pre- and post-ban slopes with the formula: $[\exp((\beta_1 + \beta_3)*52 \pm 1.96*(SQRT(Var(\sum \beta_{1,3}))*52))]$, with $Var(\sum \beta_{1,3})$ determined as $[\sum Var(\beta_{1,3}) + \sum Cov(\beta_{1,3})]$, where $\sum Var(\beta_{1,3})$ is the sum of pre- and post-ban slope variance and $\sum Cov(\beta_{1,3})$ is the sum of the pre- and post-ban slope covariance (Schwartz, 2000; Zeka et al., 2005).

All analyses were conducted using SAS version 9.2, and statistical modelling was carried out with the SAS GLIMMIX procedure, allowing adjustment for autocorrelation (SAS, 2011b).

Number of Deaths Prevented

The predicted incremental number of deaths that would have occurred in the absence of a national smoking ban for each of the 3.75 post-ban years (April 2004-December 2007) were calculated as follows:

$$\text{Predicted deaths}_i = \left[\text{Observed deaths}_j - \left(\text{Observed deaths}_j * \text{Pre-ban annual change}\right)\right]$$

where *i* represents each post-ban year, and *j* denotes the number of annual deaths from the preceding year.

Active Smoking Attributable Risk

To determine the extent to which observed mortality reductions in the first post-ban year were attributable to decreases in active smoking, the appropriate relative risks for IHD, stroke, and COPD in active and former smokers were derived from the published literature (Barone-Adesi et al., 2006; Doll et al., 2004; Kawachi et al., 1993; Kurth et al., 2003; Law & Wald, 2003; Shinton & Beevers, 1989) and applied to an adapted attributable risk formula previously published by Barone-Adesi et al. (2006). The formula was as follows:

$$Decrease\% = \left[1 - \left(\frac{(1-\text{Prev}_{\text{pre}})(\text{I}_{\text{b}}) + (\text{Prev}_{\text{pre}} - \text{Prev}_{\text{ban}})(\text{RR}_{\text{ex}})(\text{I}_{\text{b}}) + (\text{Prev}_{\text{ban}})(\text{RR}_{\text{ban}})(\text{I}_{\text{b}})}{(1-\text{Prev}_{\text{pre}})(\text{I}_{\text{b}}) + (\text{Prev}_{\text{pre}})(\text{RR}_{\text{pre}})(\text{I}_{\text{b}})}\right)\right] * 100$$

where I_b represents the model-derived background incidence rate for IHD, stroke, and COPD, $Prev_{pre}$ indicates the pre-ban prevalence of active smokers and $Prev_{ban}$ indicates the post-ban prevalence of active smokers in the first post-ban year (April 2004-April 2005), RR_{ex} represents the literature-derived relative risks in former smokers ≥5 months after cessation for IHD, stroke, and COPD, RR_{ban} represents the relative risks in active smokers associated with the mean number of cigarettes smoked per day in the first post-ban year, assuming a linear dose-response relationship, RR_{pre} represents the literature-derived relative risks in active smokers associated with the mean number of cigarettes smoked per day in the first pre-ban year (March 2003-March 2004), once again assuming a linear dose-response relationship.

To support these analyses, crude and model-estimated changes in pre- and post-ban monthly smoking prevalence were calculated to determine whether ban implementation affected smoking prevalence in the population. The change in number of cigarettes smoked per day was also assessed.

3.4. RESULTS

During the study period, 215,878 non-trauma deaths occurred in the Irish population ages ≥35 years. The population at risk was 1.9 million, mean figures from the 2002 and 2006 censuses. Crude mortality rates per 10,000 population are shown in Figure 3.2. Mortality events were equally distributed between males and females for all study years (Figure 3.3), with around half of all deaths occurring in persons aged 65-84 years (Figure 3.4).

Seasonal variations in mortality were detected, with the largest number of deaths occurring in autumn and winter. From 2000-2007, an overall decrease in mortality rates was observed for all smoking-related causes of death with decreases becoming more pronounced in the post-ban period (Figure 3.5). In contrast, non-smoking related mortality showed a sharp increase in 2006 which continued throughout the end of the study period.

From 2000-2007, five periods of increased ILI activity were identified, with the largest period of increase occurring for eight consecutive weeks in the latter part of the 2000-2001 influenza season (Figure 3.6).

Figure 3.2: Crude Mortality Rates in the Irish Population, Aged ≥35 Years, 2000-2007

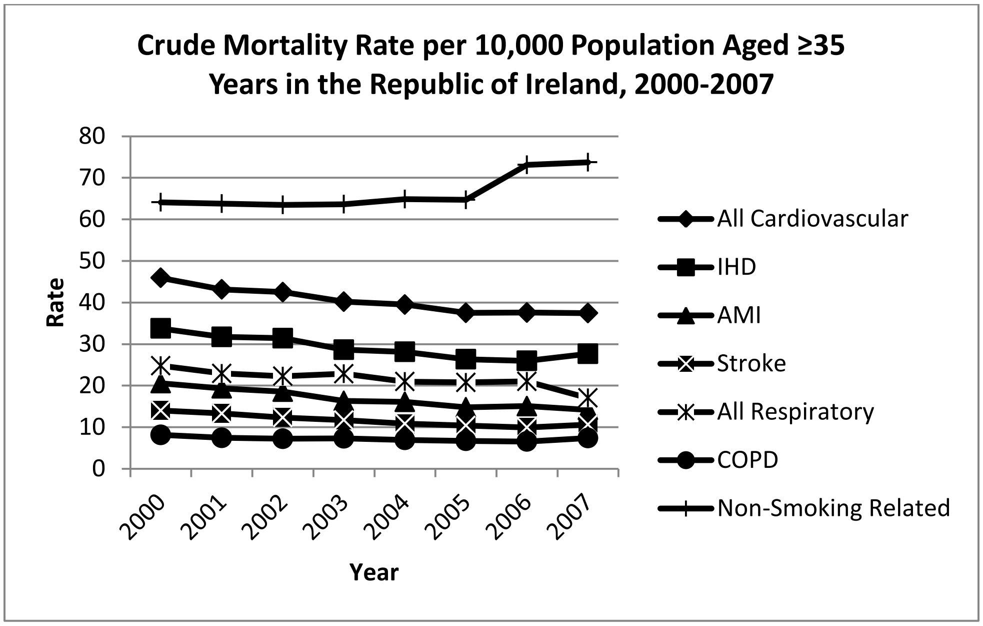


Figure 3.3: Mortality Distribution by Sex in the Irish Population, Aged ≥35 Years, 2000-2007

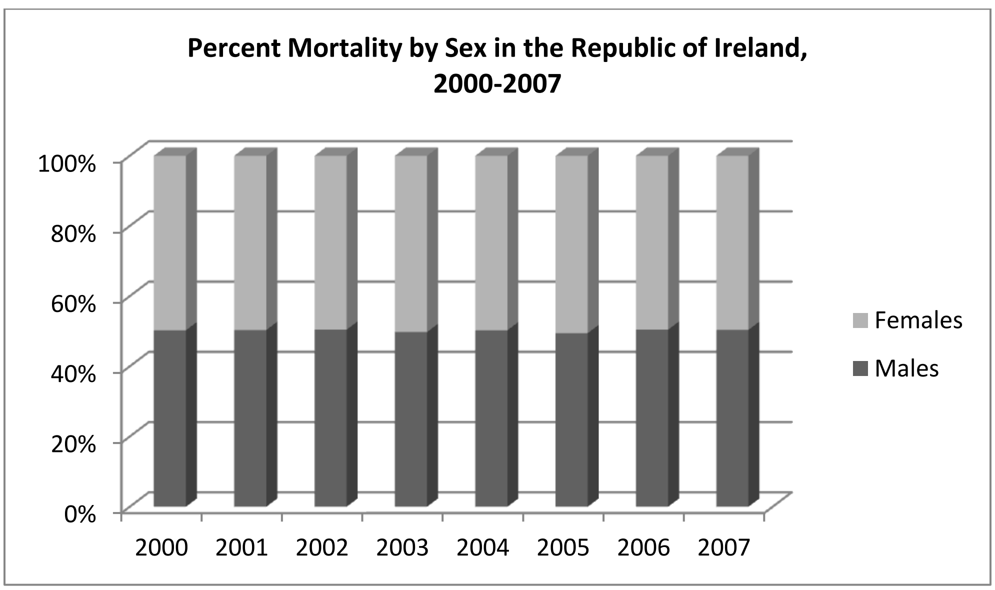


Figure 3.4: Mortality Distribution by Age Category in the Irish Population, Aged ≥35 Years, 2000-2007

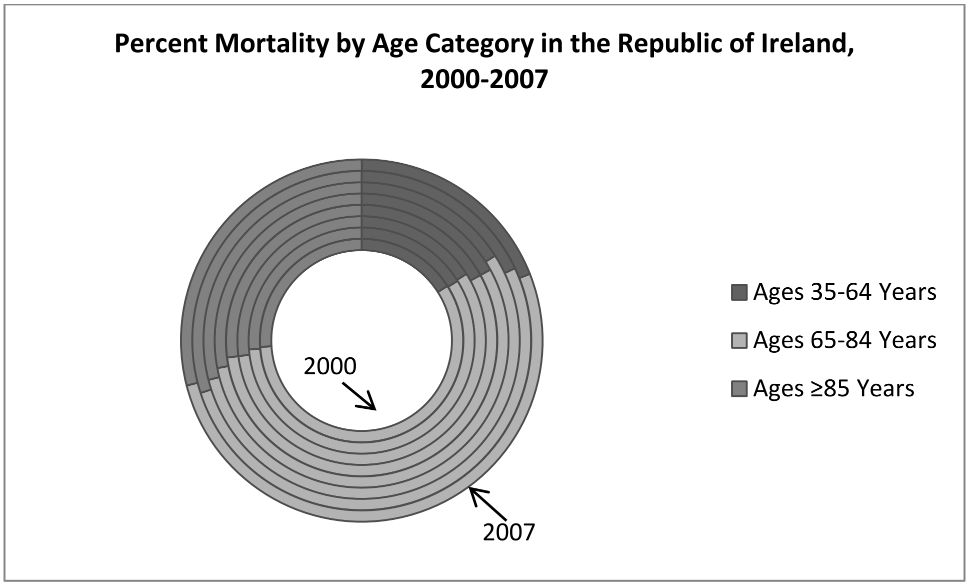


Figure 3.5: Observed Monthly Mortality in the Republic of Ireland, 2000-2007.* †‡
*All Respiratory excludes data from year 2007.
†The vertical line represents the month of smoking ban implementation.
‡Monthly mortality is displayed rather than weekly for a clearer visual representation of trends.

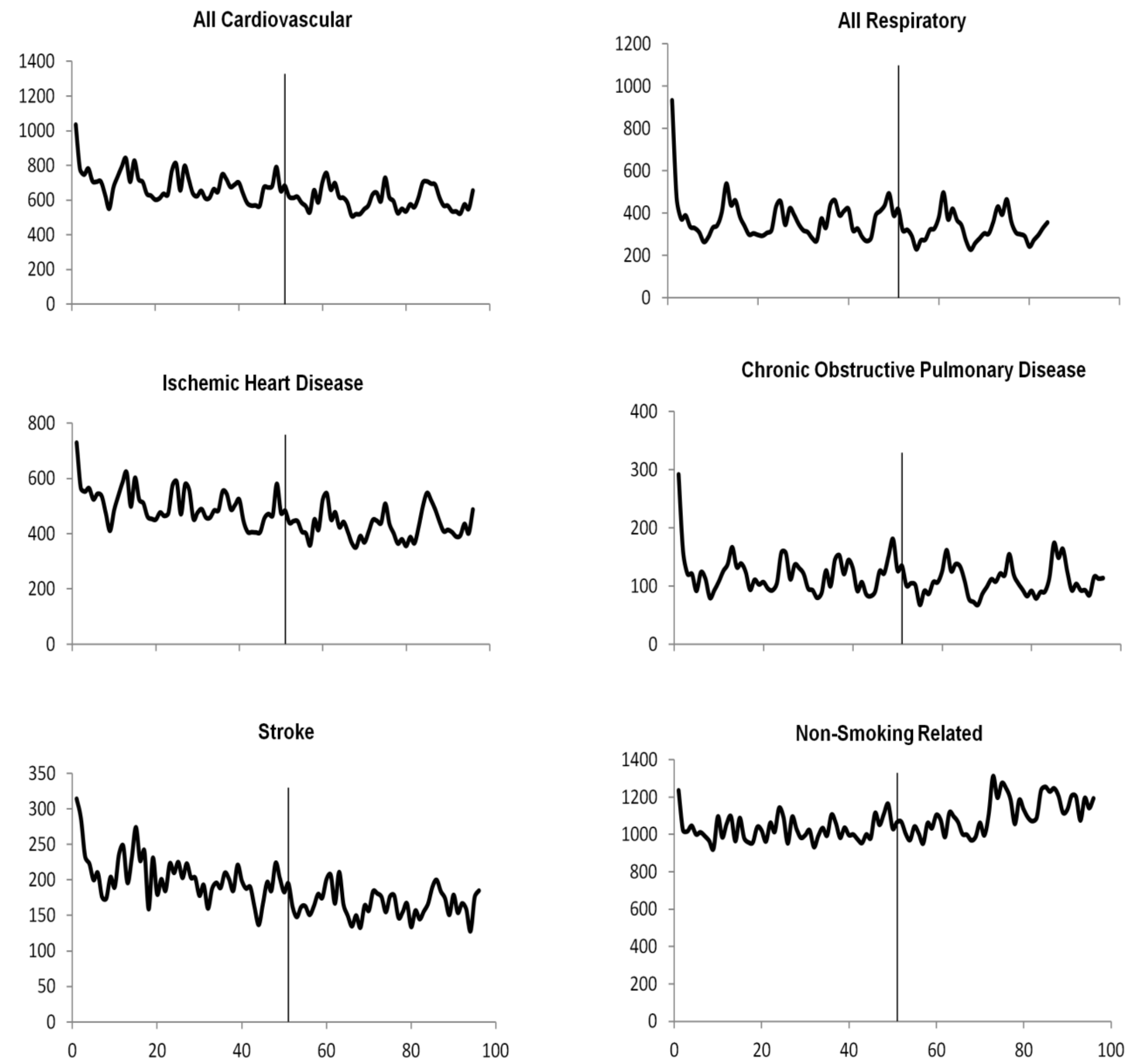
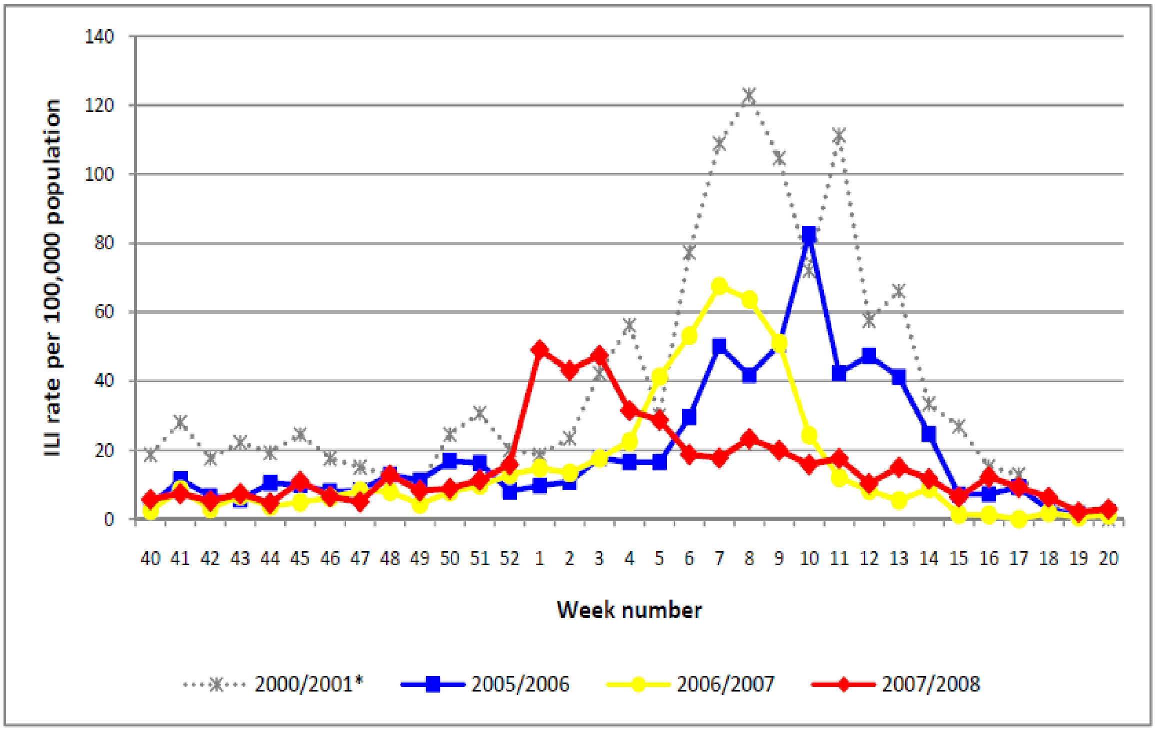


Figure 3.6: Influenza-Like Illness (ILI) Rate per 100,000 Population by Week during the 2000-2001, 2005-2006, 2006-2007, and 2007-2008 Influenza Seasons, Republic of Ireland



Source: Irish Health Protection Surveillance Centre. Summary Report of 2007/2008 Influenza Season. Retrieved September 27, 2011, from http://www.hpsc.ie/hpsc/AZ/Respiratory/Influenza/SeasonalInfluenza/Surveillance/InfluenzaSurveillanceReports/PreviousInfluenzaSeasonsSurveillanceReports/20072008Season/File,3418,en.pdf

Results of the Poisson regression analyses demonstrated that all-cause mortality rates decreased in the pre-ban period (RR: 0.98; 95% CI: 0.96-0.99). Similar pre-ban reductions were found for all cardiovascular causes, IHD, AMI, stroke, and COPD. No pre-ban mortality decreases were seen for non-smoking related mortality (Tables 3.4 and 3.5).

Table 3.4: Multivariate Analysis† of Annual Pre-Ban Changes in Overall and Gender-Specific Mortality Rates,‡ Ages ≥35 years, Republic of Ireland, 2000-2007

Cause of Death	**Overall**	**Males**	**Females**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.98 (0.96-0.99)	0.98 (0.97-1.00)	0.98 (0.96-0.99)
All Cardiovascular	0.96 (0.94-0.97)	0.95 (0.94-0.97)	0.96 (0.94-0.98)
Ischemic Heart Disease	0.95 (0.93-0.97)	0.94 (0.92-0.96)	0.96 (0.94-0.98)
Myocardial Infarction	0.94 (0.92-0.96)	0.93 (0.91-0.96)	0.94 (0.92-0.97)
Stroke	0.93 (0.91-0.95)	0.92 (0.90-0.95)	0.93 (0.91-0.96)
All Respiratory*	0.97 (0.94-0.99)	0.97 (0.94-1.00)	0.96 (0.93-0.99)
COPD	0.95 (0.92-0.99)	0.98 (0.94-1.02)	0.92 (0.89-0.97)
Non-Smoking Related Mortality	1.01 (0.99-1.02)	1.01 (0.99-1.03)	1.00 (0.99-1.02)

†Adjusted for season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.5: Multivariate Analysis† of Annual Pre-Ban Changes in Mortality Rates by Age Category,‡ Republic of Ireland, 2000-2007

Cause of Death	**Ages 35-64 Years**	**Ages 65-84 Years**	**Ages ≥85 Years**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
All Mortality	1.00 (0.98-1.02)	0.96 (0.95-0.98)	1.00 (0.98-1.02)
All Cardiovascular	0.97 (0.94-1.00)	0.94 (0.93-0.96)	0.98 (0.96-1.00)
Ischemic Heart Disease	0.95 (0.92-0.99)	0.93 (0.91-0.95)	0.98 (0.96-1.01)
Myocardial Infarction	0.92 (0.88-0.97)	0.92 (0.90-0.94)	0.99 (0.96-1.02)
Stroke	0.91 (0.85-0.97)	0.91 (0.89-0.94)	0.96 (0.93-0.99)
All Respiratory*	1.01 (0.95-1.07)	0.96 (0.93-0.98)	0.97 (0.94-1.00)
COPD	0.96 (0.87-1.05)	0.95 (0.92-0.99)	0.95 (0.90-1.00)
Non-Smoking Related Mortality	1.02 (1.00-1.05)	0.99 (0.97-1.00)	1.05 (1.03-1.07)

†Adjusted for season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Overall and gender-specific post-ban results of Poisson regression analyses are reported in Table 3.6. Following the implementation of the ban, an immediate 13% decrease in all-cause mortality was observed (RR: 0.87; 95% CI: 0.76-0.99). Likewise, an immediate 26% reduction in mortality was seen in IHD (RR: 0.74; 95% CI: 0.63-0.88), a 32% reduction in stroke (RR: 0.68; 95% CI: 0.54-0.85), and a 38% reduction in COPD (RR: 0.62; 95% CI: 0.46-0.83). IHD and stroke reductions were observed in both genders, but reductions in all respiratory mortality were seen only in females (RR: 0.64; 95% CI: 0.42-0.98) driven by reductions in COPD (RR: 0.47; 95% CI: 0.32-0.70).

In contrast, an immediate 15% decrease was observed for non-smoking related mortality (RR: 0.85; 95% CI: 0.75-0.97), followed by a 5% increase each post-ban year (RR: 1.05; 95% CI: 1.02-1.08). This resulted in a net post-ban increase of 4%. No annual trend effects in post-ban mortality were detected for any smoking-related causes of death.

Table 3.7 displays Poisson regression results stratified by age category. For ages 35-64 years, an immediate post-ban decrease in all-cause mortality was observed (RR: 0.79; 95% CI: 0.67-0.93), followed by annual trend increases in all-cause mortality (RR: 1.06; 95%: 1.02-1.10), resulting in a net post-ban increase of 2%. For ages 65-84 years, immediate decreases were seen in all-cause mortality (RR: 0.87; 95% CI: 0.75-0.99). Similar immediate decreases were observed in IHD, stroke, and COPD for ages 65-84 years and for ages ≥85 years.

The inclusion of additional post-ban indicator variables at one, three, six, and twelve months implied only short-term ban effects (Tables 3.8 and 3.9). The testing of false ban implementation dates showed that immediate mortality effects were either non-significant or smaller in magnitude compared to actual ban effects (Table 3.10). Only AMI showed a larger effect with the false date of one year pre-ban which coincided with the announcement by the Irish Minister for Health that a ban was to come into force on March 29, 2004.

Table 3.6: Multivariate Analysis† of Overall and Gender-Specific Post-Ban Effects on Mortality Rates‡, Ages ≥35 years, Republic of Ireland, 2000-2007

	Overall		Males		Females	
Cause of Death	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All-Cause Mortality	0.87 (0.76-0.99)	1.01 (0.98-1.05)	0.87 (0.76-1.00)	1.01 (0.98-1.05)	0.86 (0.74-0.99)	1.01 (0.98-1.05)
All Cardiovascular	0.86 (0.74-1.00)	0.99 (0.95-1.03)	0.85 (0.72-1.02)	0.99 (0.95-1.03)	0.87 (0.72-1.04)	0.99 (0.95-1.04)
Ischemic Heart Disease	0.74 (0.63-0.88)	1.00 (0.96-1.04)	0.71 (0.58-0.86)	1.01 (0.96-1.05)	0.79 (0.64-0.97)	1.00 (0.95-1.05)
Acute Myocardial Infarction	0.89 (0.74-1.08)	0.97 (0.92-1.02)	0.87 (0.70-1.10)	0.97 (0.91-1.02)	0.92 (0.71-1.18)	0.97 (0.91-1.03)
Stroke	0.68 (0.54-0.85)	1.00 (0.95-1.05)	0.66 (0.49-0.89)	0.99 (0.92-1.06)	0.69 (0.53-0.91)	1.01 (0.94-1.07)
All Respiratory*	0.77 (0.54-1.10)	1.01 (0.92-1.10)	0.93 (0.63-1.38)	0.98 (0.89-1.07)	0.64 (0.42-0.98)	1.04 (0.94-1.14)
COPD	0.62 (0.46-0.83)	1.03 (0.96-1.11)	0.78 (0.55-1.12)	1.01 (0.92-1.09)	0.47 (0.32-0.70)	1.07 (0.97-1.16)
Non-Smoking Related Mortality	0.85 (0.75-0.97)	1.05 (1.02-1.08)	0.85 (0.73-1.00)	1.06 (1.02-1.09)	0.84 (0.71-0.99)	1.04 (1.00-1.08)

†Adjusted for time trend, season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.7: Multivariate Analysis† of Post-Ban Effects on Mortality Rates by Age Category‡, Republic of Ireland, 2000-2007

	Ages 35-64 Years		Ages 65-84 Years		Ages ≥85 Years	
Cause of Death	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All-Cause Mortality	0.79 (0.67-0.93)	1.06 (1.02-1.10)	0.87 (0.75-0.99)	0.99 (0.96-1.03)	0.94 (0.80-1.10)	1.02 (0.98-1.06)
All Cardiovascular	0.91 (0.69-1.20)	0.98 (0.91-1.05)	0.86 (0.73-1.02)	0.97 (0.93-1.01)	0.86 (0.70-1.05)	1.03 (0.98-1.08)
Ischemic Heart Disease	0.74 (0.53-1.02)	1.01 (0.93-1.08)	0.74 (0.61-0.89)	0.98 (0.94-1.03)	0.78 (0.62-0.99)	1.04 (0.99-1.10)
Acute Myocardial Infarction	0.89 (0.58-1.36)	0.97 (0.86-1.07)	0.90 (0.71-1.13)	0.94 (0.89-1.00)	0.94 (0.71-1.26)	1.01 (0.94-1.09)
Stroke	0.66 (0.37-1.18)	1.00 (0.86-1.14)	0.75 (0.57-0.99)	0.96 (0.90-1.03)	0.61 (0.44-0.83)	1.05 (0.97-1.13)
All Respiratory*	1.59 (0.75-3.39)	0.93 (0.75-1.11)	0.71 (0.47-1.05)	1.01 (0.91-1.10)	0.75 (0.48-1.17)	1.03 (0.92-1.14)
COPD	0.74 (0.32-1.72)	1.04 (0.83-1.24)	0.68 (0.48-0.96)	1.01 (0.92-1.09)	0.49 (0.31-0.78)	1.09 (0.98-1.20)
Non-Smoking Related Mortality	0.72 (0.60-0.86)	1.10 (1.06-1.14)	0.86 (0.75-1.00)	1.03 (0.99-1.06)	1.03 (0.85-1.25)	1.05 (1.01-1.10)

†Adjusted for time trend, season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.8: Short-Term Mortality Effects of the National Smoking Ban in the Republic of Ireland, Implemented 29 March 2004, Ages ≥35 Years, 2000-2007[†‡]

	One Month Post-Ban			**Three Months Post-Ban**		
Cause of Death	**Effects in One Month**	**Immediate Effects**	**Gradual Effects per Annum**	**Effects in Three Months**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.98 (0.88-1.10)	0.87 (0.76-1.00)	1.01 (0.98-1.05)	0.99 (0.91-1.06)	0.88 (0.76-1.01)	1.01 (0.98-1.05)
All Cardiovascular	0.97 (0.85-1.10)	0.87 (0.75-1.02)	0.99 (0.95-1.03)	1.02 (0.93-1.11)	0.85 (0.72-1.01)	0.99 (0.95-1.03)
Ischemic Heart Disease	0.99 (0.86-1.14)	0.75 (0.63-0.88)	1.00 (0.96-1.04)	1.07 (0.97-1.17)	0.70 (0.58-0.84)	1.01 (0.97-1.05)
Acute Myocardial Infarction	0.97 (0.83-1.15)	0.90 (0.74-1.10)	0.97 (0.92-1.02)	1.05 (0.94-1.17)	0.86 (0.69-1.06)	0.97 (0.92-1.02)
Stroke	1.02 (0.84-1.23)	0.67 (0.53-0.85)	1.00 (0.95-1.06)	0.98 (0.86-1.11)	0.69 (0.54-0.89)	1.00 (0.94-1.06)
All Respiratory*	0.91 (0.73-1.13)	0.82 (0.56-1.20)	1.00 (0.91-1.09)	0.98 (0.84-1.14)	0.80 (0.52-1.24)	1.00 (0.90-1.11)
COPD	0.94 (0.73-1.22)	0.63 (0.47-0.86)	1.03 (0.96-1.11)	1.05 (0.88-1.25)	0.60 (0.43-0.83)	1.04 (0.96-1.12)
Non-Smoking Related Mortality	1.03 (0.92-1.15)	0.84 (0.74-0.96)	1.05 (1.02-1.08)	1.00 (0.92-1.07)	0.85 (0.74-0.99)	1.05 (1.01-1.08)

[†]Adjusted for time trend, season, influenza, and smoking prevalence.
[‡]Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.9: Longer-Term Effects of the National Smoking Ban in the Republic of Ireland, Implemented 29 March 2004, Ages ≥35 Years, 2000-2007†‡

	Six Months Post-Ban			**Twelve Months Post-Ban**		
Cause of Death	**Effects in Six Months**	**Immediate Effects**	**Gradual Effects per Annum**	**Effects in Twelve Months**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.97 (0.91-1.03)	0.91 (0.77-1.07)	1.01 (0.97-1.04)	1.00 (0.94-1.06)	0.86 (0.71-1.04)	1.01 (0.97-1.06)
All Cardiovascular	1.00 (0.93-1.07)	0.87 (0.72-1.05)	0.99 (0.95-1.03)	1.06 (0.99-1.14)	0.74 (0.60-0.93)	1.01 (0.96-1.06)
Ischemic Heart Disease	1.02 (0.95-1.11)	0.72 (0.58-0.88)	1.01 (0.96-1.06)	1.10 (1.02-1.19)	0.60 (0.47-0.76)	1.03 (0.98-1.09)
Acute Myocardial Infarction	0.98 (0.89-1.08)	0.92 (0.72-1.17)	0.97 (0.91-1.02)	1.05 (0.97-1.15)	0.79 (0.59-1.05)	0.99 (0.92-1.05)
Stroke	1.02 (0.91-1.13)	0.66 (0.50-0.88)	1.00 (0.94-1.07)	1.13 (1.02-1.25)	0.51 (0.37-0.71)	1.04 (0.97-1.11)
All Respiratory*	0.87 (0.76-1.01)	1.17 (0.67-2.02)	0.96 (0.83-1.08)	1.04 (0.89-1.21)	0.67 (0.33-1.34)	1.03 (0.88-1.19)
COPD	0.98 (0.84-1.13)	0.64 (0.45-0.93)	1.03 (0.95-1.11)	1.10 (0.96-1.26)	0.50 (0.33-0.76)	1.07 (0.97-1.16)
Non-Smoking Related Mortality	0.99 (0.93-1.05)	0.87 (0.74-1.02)	1.05 (1.01-1.08)	0.97 (0.92-1.03)	0.90 (0.75-1.09)	1.04 (1.00-1.08)

†Adjusted for time trend, season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.10: Multivariate Analysis† of Effects on Mortality Rates‡ in Ages ≥35 years with the Use of False Ban Dates, Republic of Ireland, 2000-2007

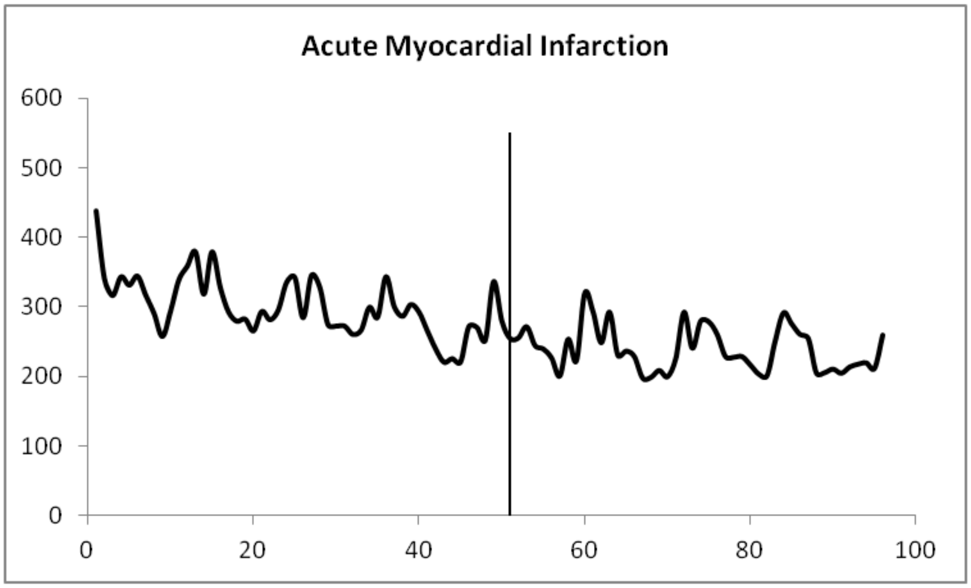
	False Ban Date 1 (2 years pre-ban)		**False Ban Date 2 (1 year pre-ban)**		**False Ban Date 3 (6 months pre-ban)**	
Cause of Death	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.88 (0.83-0.94)	1.01 (0.96-1.06)	0.90 (0.83-0.97)	1.01 (0.98-1.04)	0.93 (0.84-1.03)	1.01 (0.98-1.03)
All Cardiovascular	0.90 (0.84-0.97)	0.98 (0.93-1.04)	0.90 (0.82-0.98)	0.99 (0.95-1.02)	0.91 (0.81-1.03)	0.98 (0.95-1.02)
Ischemic Heart Disease	0.90 (0.83-0.97)	0.98 (0.92-1.04)	0.83 (0.75-0.92)	0.99 (0.95-1.03)	0.81 (0.72-0.92)	0.99 (0.96-1.03)
Acute Myocardial Infarction	0.91 (0.83-0.99)	0.97 (0.90-1.03)	0.85 (0.76-0.96)	0.97 (0.93-1.02)	0.89 (0.77-1.04)	0.97 (0.93-1.01)
Stroke	0.86 (0.78-0.96)	0.97 (0.90-1.05)	0.81 (0.71-0.93)	0.98 (0.93-1.03)	0.78 (0.66-0.92)	0.99 (0.94-1.03)
All Respiratory*	0.91 (0.81-1.03)	0.98 (0.90-1.06)	1.02 (0.86-1.22)	0.97 (0.91-1.04)	1.05 (0.83-1.34)	0.97 (0.90-1.03)
COPD	0.84 (0.73-0.96)	1.00 (0.89-1.10)	0.84 (0.70-1.00)	1.00 (0.93-1.07)	0.85 (0.68-1.06)	1.00 (0.93-1.06)
Non-Smoking Related Mortality	0.86 (0.81-0.91)	1.05 (1.00-1.09)	0.87 (0.79-0.96)	1.05 (1.01-1.08)	0.90 (0.80-1.02)	1.04 (1.01-1.08)

†Adjusted for season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

This presented the question of whether increased awareness of ban implementation and the concurrent media attention resulted in systematic bias of recording primary causes of death. To further investigate this possibility, diabetes and AMI were selected for contemporaneous analyses to determine if the coding of primary cause of death in any way strategically increased for a non-smoking related cause while decreasing for a smoking-related cause. If bias in the recording of primary cause of death was present, then an immediate increase in diabetes would be expected post-ban, associated with an immediate decrease of AMI deaths in the same period. As Figure 3.7 shows, no observable increase in diabetes as the primary cause of death occurred in the first post-ban year, the period during which AMI effects were found. A Poisson regression model of monthly diabetes mortality also confirmed this finding with a pre-ban trend rate ratio (RR) of 1.03 (95% CI: 0.99-1.08), a post-ban immediate effects RR of 1.12 (95% CI: 0.78-1.62), and a gradual effects per annum RR of 1.04 (95% CI: 0.94-1.13). Because AMI declines were also observed one year prior to the ban, a similar false ban date of one year pre-ban was tested for diabetes. The results of the Poisson regression model detected no one year pre-ban trend (RR=0.98; 95% CI: 0.92-1.04), immediate effect (RR=0.96; 95% CI: 0.77-1.20), or gradual trend effects (RR=1.05; 95% CI: 0.95-1.15). Therefore, systematic coding bias seems unlikely.

Additional sensitivity analyses demonstrated that model results were largely unaffected by the 1999-2000 winter peak in mortality, with no differences in the direction of effects observed for any smoking-related causes of death (Tables 3.11 and 3.12). Seasonal adjustment with annual and semi-annual sine and cosine terms yielded similar effects to adjustment with calendar months (Figure 3.8 and Table 3.13).

Figure 3.7: Monthly Mortality Comparison between Acute Myocardial Infarction and Diabetes in the Republic of Ireland, 2000-2007



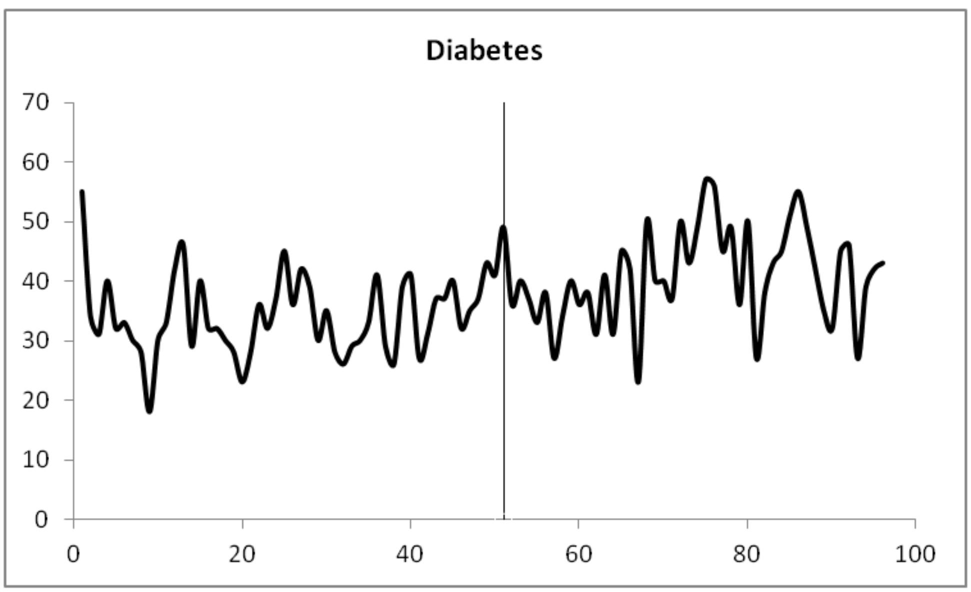


Table 3.11: Multivariate Analysis† of Overall Changes in Mortality Rates,‡ Ages ≥35 years, Republic of Ireland, Including Winter 1999-2000 (from week 48 of 1999 to week 51 of 2007)

	Pre-Ban	**Post-Ban**	
Cause of Death	**Pre-Ban Annual Change**	**Post-Ban Step Change**	**Post-Ban Annual Slope Change**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.98 (0.97-1.00)	0.85 (0.72-1.00)	1.01 (0.98-1.05)
All Cardiovascular	0.96 (0.94-0.97)	0.85 (0.70-1.02)	0.99 (0.95-1.03)
Ischemic Heart Disease	0.95 (0.93-0.97)	0.72 (0.58-0.88)	1.00 (0.96-1.04)
Acute Myocardial Infarction	0.94 (0.92-0.96)	0.88 (0.70-1.11)	0.97 (0.92-1.02)
Stroke	0.93 (0.91-0.95)	0.64 (0.49-0.83)	1.00 (0.95-1.06)
All Respiratory*	0.97 (0.94-0.99)	0.77 (0.49-1.20)	1.00 (0.91-1.09)
COPD	0.95 (0.92-0.98)	0.58 (0.40-0.83)	1.03 (0.96-1.11)
Non-Smoking Related Mortality	1.01 (0.99-1.03)	0.84 (0.69-1.02)	1.05 (1.01-1.09)

†Adjusted for season, influenza, and smoking prevalence. ‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Table 3.12: Multivariate Analysis† of Overall Changes in Mortality Rates,‡ Ages ≥35 years, Republic of Ireland, Excluding Winter 1999-2000 (from week 14 of 2000 to week 51 of 2007)

	Pre-Ban	**Post-Ban**	
Cause of Death	**Pre-Ban Annual Change**	**Post-Ban Step Change**	**Post-Ban Annual Slope Change**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
All Mortality	1.00 (0.98-1.01)	0.92 (0.81-1.05)	1.01 (0.98-1.04)
All Cardiovascular	0.97 (0.95-0.99)	0.90 (0.78-1.05)	0.99 (0.95-1.03)
Ischemic Heart Disease	0.96 (0.94-0.98)	0.77 (0.65-0.90)	1.00 (0.96-1.05)
Myocardial Infarction	0.94 (0.92-0.96)	0.90 (0.74-1.10)	0.97 (0.92-1.02)
Stroke	0.95 (0.93-0.98)	0.74 (0.59-0.92)	1.00 (0.94-1.06)
All Respiratory*	1.01 (0.98-1.04)	0.93 (0.68-1.27)	1.00 (0.93-1.08)
COPD	0.99 (0.96-1.03)	0.72 (0.54-0.95)	1.03 (0.96-1.10)
Non-Smoking Related Mortality	1.02 (1.00-1.03)	0.88 (0.77-1.01)	1.05 (1.02-1.08)

†Adjusted for season, influenza, and smoking prevalence. ‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

Figure 3.8: Seasonal Adjustments with Annual and Semi-Annual Sine/Cosine Terms versus Calendar Months, Predicted Weekly Stroke Deaths in the Irish Population, Aged ≥35 Years, 2000-2007

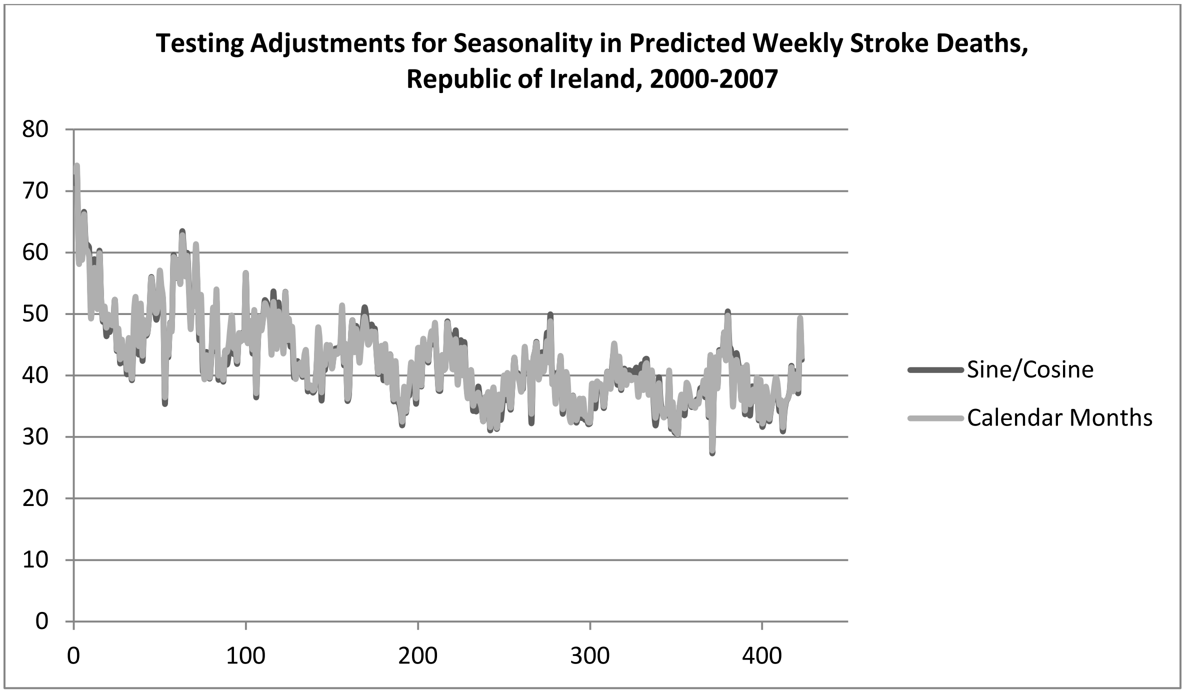


Table 3.13: Multivariate Analysis† of Overall Changes in Mortality Rates with Adjustment for Season Using Annual and Semi-Annual Sine and Cosine Terms,‡ Ages ≥35 years Republic of Ireland, 2000-2007

	Pre-Ban	**Post-Ban**	
Cause of Death	**Pre-Ban Annual Change**	**Post-Ban Step Change**	**Post-Ban Annual Slope Change**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
All Mortality	0.98 (0.97-0.99)	0.88 (0.78-1.00)	1.01 (0.98-1.04)
All Cardiovascular	0.96 (0.94-0.97)	0.88 (0.76-1.02)	0.99 (0.95-1.02)
Ischemic Heart Disease	0.95 (0.93-0.97)	0.76 (0.65-0.89)	1.00 (0.96-1.04)
Myocardial Infarction	0.94 (0.92-0.96)	0.91 (0.76-1.10)	0.97 (0.92-1.01)
Stroke	0.93 (0.91-0.95)	0.70 (0.56-0.87)	1.00 (0.95-1.05)
All Respiratory*	0.97 (0.94-0.99)	0.83 (0.59-1.17)	1.00 (0.92-1.08)
COPD	0.96 (0.93-0.99)	0.65 (0.49-0.87)	1.03 (0.96-1.10)
Non-Smoking Related Mortality	1.01 (0.99-1.02)	0.86 (0.76-0.98)	1.05 (1.02-1.08)

†Adjusted for season, influenza, and smoking prevalence.
‡Age and gender-standardised according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.

In the absence of a national smoking ban, an estimated 3,726 (95% CI: 2,305-4,629) additional smoking-related deaths would have occurred. This crude estimate indicates that reductions occurred in respiratory (up to 2006, 1,896 deaths; 95% CI: 1,517-2,152), cardiovascular (1,508 deaths; 95% CI: 690-1,926), and stroke mortality (322; 95% CI: 98-552). No deaths were prevented in association with non-smoking related mortality.

In concurrence with the findings of the active smoking attributable risk calculation for AMI in the Italian population, as conducted by Barone-Adesi et al. (2006), the pre-ban and post-ban relative risks were similar because the mean number of cigarettes smoked per day did not appreciably differ. Thus, the attributable risk calculations for IHD, stroke, and COPD respectively demonstrated that <1% of smoking ban effects was due to decreases in active smoking. Therefore, the resulting mortality decreases following smoking ban implementation were primarily due to reductions in passive smoking.

Additional analyses assessing the change in smoking prevalence in the Irish population as a result of ban implementation showed no observable effects. Figures 3.9, 3.10, and 3.11 display monthly smoking prevalence in ages ≥15 years for all, males, and females respectively, from July 2002 to December 2007, the time period in which data were available. Figure 3.12 shows the change in mean number of cigarettes smoked per day comparing pre- and post-ban periods.

Although the figures show a small smoking prevalence effect in the year before the ban, most likely due to increased media attention regarding impending ban implementation, the reduction was not statistically significant ($p=0.81$). Crude percent calculations demonstrated that smoking prevalence decreased by 1.78% in the two years following the ban (-2.63% for males and -1.04% for females) as compared to one year pre-ban. However, a Poisson regression model with monthly smoking prevalence as the outcome detected no ban effects ($\beta2= -0.16$; SE=0.20). The change in mean number of cigarettes smoked per day comparing pre- and post-ban periods was less than that of the smoking prevalence.

Therefore, by adjusting for smoking prevalence in all models, the more extreme scenario was considered, further validating the robustness of model estimates of the ban effect.

Figure 3.9: Monthly Smoking Prevalence in Ages ≥15 Years, Republic of Ireland, July 2002-December 2007

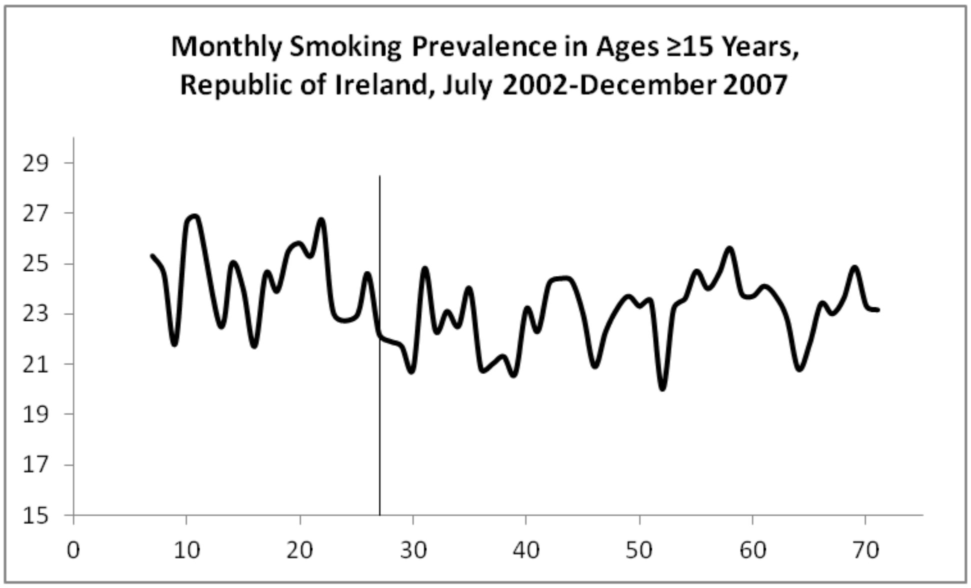


Figure 3.10: Monthly Smoking Prevalence in Males, Ages ≥15 Years, Republic of Ireland, July 2002-December 2007

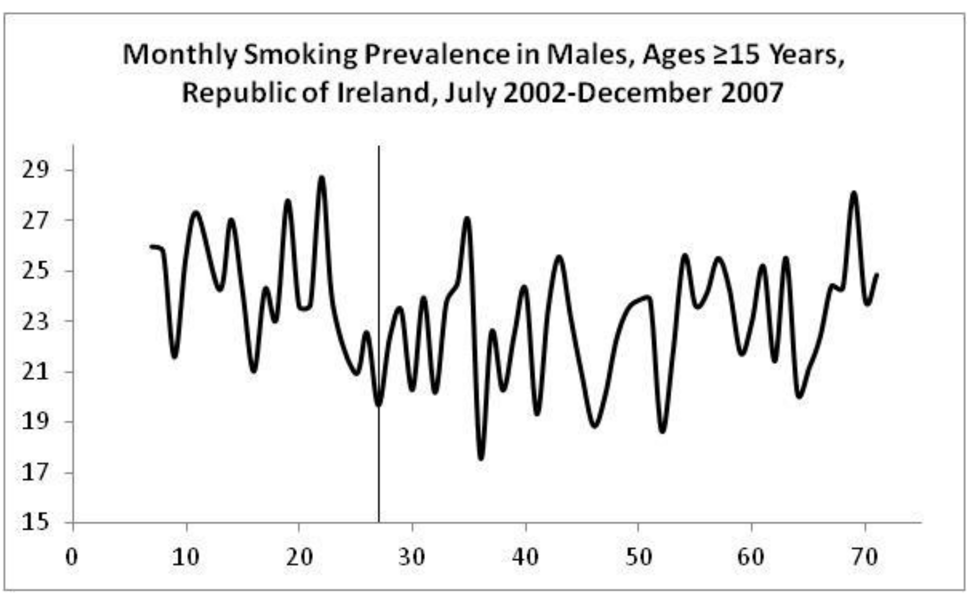


Figure 3.11: Monthly Smoking Prevalence in Females, Ages ≥15 Years, Republic of Ireland, July 2002-December 2007

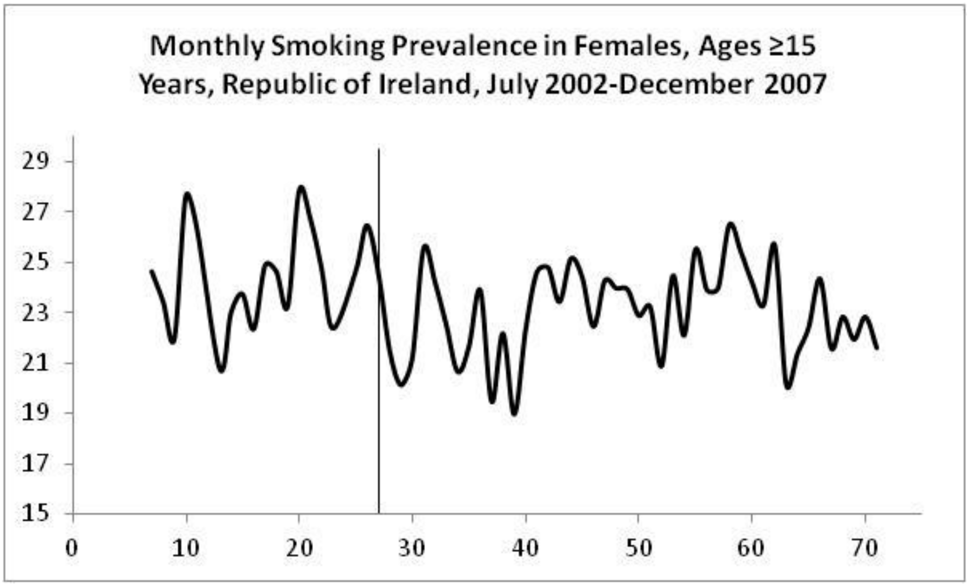
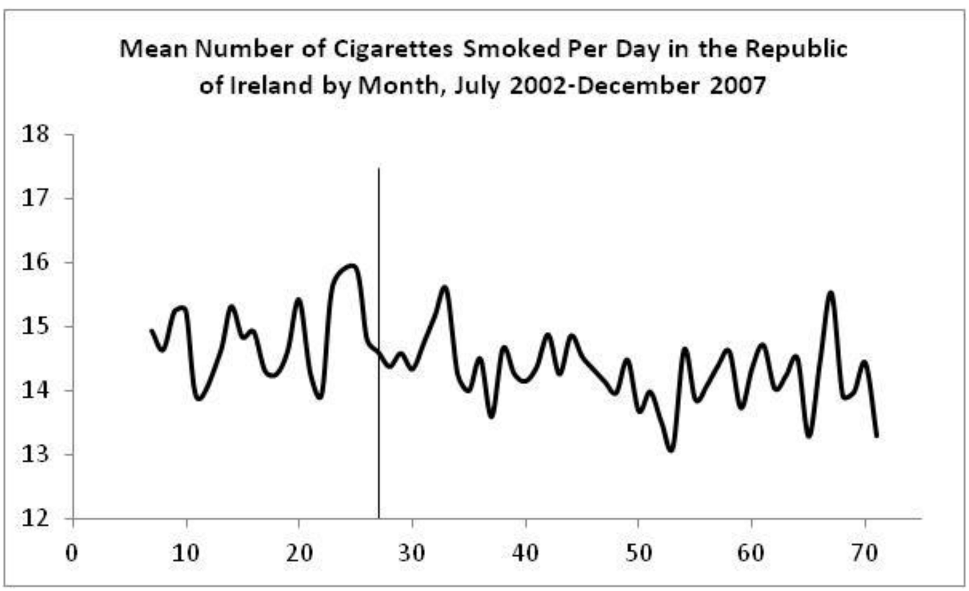


Figure 3.12: Mean Number of Cigarettes Smoked per Day in Ages ≥15 Years, Republic of Ireland, July 2002-December 2007



3.5. DISCUSSION

The implementation of a national comprehensive smoking ban in the Republic of Ireland was associated with immediate mortality reductions in the population aged ≥35 years. After adjusting for time trend, seasonal variation, periods of high influenza activity, and national smoking prevalence, immediate post-ban reductions were observed in all-cause, IHD, stroke, and COPD mortality, indicating that the immediate removal of exposure to passive smoking was effective in preventing early mortality in the population most at risk.

No gradual post-ban trend effects were seen in any smoking-related causes of death. These findings are compatible with a similarly-designed analysis of the effects of the Scottish national smoking ban on pregnancy complications, which detected immediate step change reductions, but no gradual effects (Mackay et al., 2012). Importantly, the most recent meta-analysis of smoking ban health effect studies demonstrated that post-ban risk differences in cardiovascular deaths and hospital admissions for cardiovascular, cerebrovascular, and respiratory diseases did not change with a longer follow-up period (Tan & Glantz, 2012). This provides strong epidemiological evidence that smoking ban effects are seen immediately rather than gradually.

The decreases in IHD and stroke mortality were evident in both genders, while decreases in all respiratory and COPD mortality were noted for females. Stratification by age categories demonstrated cause-specific reductions for IHD, stroke, and COPD in ages ≥65 years. In contrast, for non-smoking related mortality both immediate post-ban reductions and gradual trend effects were detected, resulting in an overall post-ban increase.

The post-ban IHD reductions are consistent with the findings of two Irish studies, one of which demonstrated 12% reductions in hospital admissions due to acute coronary syndrome (ACS) in the first year following smoking ban implementation, with further reductions of 13% in the third post-ban year (Cronin et al., 2012) and the other which showed an 18% decrease in ACS admissions for the oldest age groups (50-69 years) in the two post-ban years compared to the two pre-ban years (Kent et al., 2012). Additional corroborative evidence from other countries includes decreases in out-of-hospital deaths due to acute coronary events for ages 35-64 years (15%) and ages 65-74 years (16%) one year following implementation of the Italian national smoking ban (Cesaroni et al., 2008) and a 6% decrease in out-of-hospital ACS deaths in the 10 months following implementation of the Scottish national smoking ban (Pell et al., 2008).

This study has been the first to demonstrate post-ban reductions in stroke mortality. These findings are corroborated by prior studies reporting post-ban reductions in stroke hospital admissions. One study assessing the effects of a three-phase, province-wide smoking ban in Ontario, Canada, reported a 24% reduction in stroke hospital admissions following the second phase of the legislation, which expanded the existing partial workplace ban to include restaurants (Naiman et al., 2010). A study evaluating the effects of the Arizona statewide smoking ban demonstrated decreases in hospital admissions due to acute stroke (14%; p=0.001) in the first post-ban year for counties that did not have prior local smoking legislation in place (Herman & Walsh, 2011). Although a study of the effects of the New York statewide smoking ban found no effects in stroke admissions in the first post-ban year, the authors suggested that previously enforced local smoking restrictions resulted in low secondhand smoke exposure among residents (Juster et al., 2007).

This has also been the first study to report smoking ban effects on respiratory mortality, with decreases in all respiratory mortality detected in females and decreases in COPD mortality detected overall, in females, and in persons aged ≥65 years. Although COPD is a chronic disease, its exacerbations are acute events that often result in admission to hospital or death. Decreased exposure to passive smoking leads to decreased exacerbations of COPD; therefore, the immediate decreases in post-ban mortality reflect an immediate delay of early COPD mortality. Hence, the implementation of the smoking ban possibly resulted in a delay of COPD deaths that would have otherwise occurred in absence of the ban. These findings are supported by a study that reported overall decreases in COPD hospital admissions following a province-wide smoking ban in Ontario, Canada (Naiman et al., 2010). Although a recent Irish study did not find post-ban decreases in COPD hospital admissions in the two post-ban years compared to the two pre-ban years, a 15% decrease in overall pulmonary admissions was detected in the same period (Kent et al., 2012).

The public health importance of the Irish national smoking ban is strongly demonstrated in estimates of the number of deaths prevented in the post-ban years. There were 3,726 fewer smoking-related deaths than would have been expected in the absence of a smoking ban. This number of prevented deaths is slightly attenuated when compared to the immediate percent reductions represented by the model, considering that model estimates account for gradual trends and other contributing factors.

The results of the attributable risk calculations for IHD mortality, which demonstrated that <1% of smoking ban effects was due to decreases in active smoking, are in concurrence with the findings of two studies that assessed the cardiovascular health effects of the national Italian smoking ban (Barone-Adesi et al., 2006; Cesaroni et al., 2008). These studies showed that 0.7% of the estimated post-ban reductions in hospital admissions due to AMI (Barone-Adesi et al., 2006) and <2% of the estimated post-ban reductions in hospital admissions and out-of-hospital deaths due to acute coronary events (Cesaroni et al., 2008) were due to changes in active smoking in the first post-ban year.

Attributable risk calculations also showed that reductions in active smoking accounted for <1% of post-ban reductions in stroke and COPD mortality, but no corroborative studies are available to make comparisons as this is the first study to assess post-ban effects in these mortality outcomes. Nevertheless, these results were supported in that no observable change in smoking prevalence was seen in Ireland as a result of the ban. Together, these findings suggest that mortality benefits were the result of reductions in exposure to passive smoking.

Rapid physiological changes occur within minutes to hours of exposure to passive smoke, increasing risk of adverse cardiovascular and cardiopulmonary events (Pechacek & Babb, 2004; Pope et al., 2009) and resulting in effects in non-smokers that are 80% to 90% as large as those experienced by chronic, active smokers (Barnoya & Glantz, 2005). Exposure to even low levels of passive smoke decreases oxygen delivery to the heart as the carbon monoxide from cigarette smoke competes with oxygen for binding sites on red blood cells (Glantz & Parmley, 1995). This impaired oxygen delivery to the heart particularly affects persons with existing cardiovascular disease, increasing arrhythmias and causing ischemia (Glantz & Parmley, 1995). This and other related evidence has resulted in the recommendation that clinicians advise the families of patients with existing cardiovascular disease not to smoke while the patient is present (Law & Wald, 2003; Pechacek & Babb, 2004). The implementation of the national Irish smoking ban resulted in an immediate removal of exposure to passive smoke in workplaces and public places, therefore likely reducing population risk of experiencing the aforementioned triggers of an adverse cardiovascular or cardiopulmonary event, particularly for those with existing disease.

Information from the Survey of Lifestyle, Attitudes, and Nutrition (SLÁN), a national survey of the Irish population ages ≥18 years, was used to investigate trends in cardiovascular and respiratory risk factors over the study period. For the years 1998 and 2002, SLÁN data were collected through self-administered, postal questionnaires, but in 2007, data were collected through face-to-face interviews conducted in the homes of respondents. As such, 2007 figures may not be directly comparable to those of previous survey waves. However, obesity prevalence and levels of physical activity remained steady across the study period. The percentage of persons consuming over the recommended weekly alcohol limit decreased in the 2007 survey wave; however, this result should be interpreted with caution as persons may have been less likely to report high levels of alcohol consumption in face-to-face interviews (Bowling, 2005).

Due to excise tax increases in Ireland, cigarettes prices increased by more than 10% in 2000, 2003, and 2007; however, the estimated effects on smokers aged ≥35 years were minimal (Currie et al., 2012). In 2002, Ireland adopted non-graphic, non-pictorial, health warnings for cigarette packages, and extended the existing TV and print media advertising ban to include selected types of indirect advertising (Currie et al., 2012). The advertising ban was further extended in 2004, but product placements and certain forms of sponsorship were still allowed (Currie et al., 2012). Although these additional tobacco control interventions may have resulted in synergistic health improvements with the national smoking ban, their estimated effects were small and gradual and are thus insufficient to explain the large mortality reductions detected immediately following the implementation of the national smoking ban.

A few limitations of this study should be addressed. Direct adjustments for weather were not possible due to the small number of weekly mortality events remaining after stratification by age, gender, and region. Nonetheless, adjustment for seasonal variation in all models partially accounts for weather effects. Likewise, data limitations prevented assignment of air pollution measures to individual mortality events. However, following implementation of a series of coal bans across Ireland's major cities from 1990-2000, large declines in black smoke were noted (Goodman et al., 2009a), along with subsequent reductions in cardiovascular and respiratory mortality in Dublin (Clancy et al., 2002). These air quality improvements may partly explain the pre-ban mortality decreases detected in this study.

A key strength of this study was the use of time-series analysis, which accounts for secular trends by design and is therefore the strongest method for assessing the effects of a broad-based intervention such as a national policy change (Wagner et al., 2002). Additionally, this study was unique in that post-ban effects in multiple causes of death were examined, including deaths due to cerebrovascular and respiratory diseases which have not been reported in any prior studies, and the post-ban follow-up period was more extensive than any other previously reported in a national population-wide assessment of a smoking ban policy.

3.6. CONCLUSION

The national smoking ban in the Republic of Ireland was associated with immediate reductions in early mortality, with specific benefits observed in cardiovascular, cerebrovascular, and respiratory causes. Importantly, post-ban risk differences did not change with a longer follow-up period. As a result of the ban, unadjusted estimates indicate that 3,726 smoking-related deaths were likely prevented. This study provides further evidence of the large public health impacts of smoking ban legislation.

CHAPTER 4: Socioeconomic Differentials in the Immediate Mortality Effects of the National Irish Smoking Ban

4.1. ABSTRACT

Background: Consistent evidence has demonstrated that smoking ban policies save lives, but impacts on health inequalities are uncertain as few studies have assessed post-ban effects by socioeconomic status (SES) and findings have been inconsistent. The aim of this study was to assess the effects of the national Irish smoking ban on ischemic heart disease (IHD), stroke, and chronic obstructive pulmonary disease (COPD) mortality by discrete and composite SES indicators to determine impacts on inequalities.

Methods: Census data were used to assign frequencies of structural and material SES indicators to 34 local authorities across Ireland with a 2000-2010 study period. Discrete indicators were jointly analysed through principal component analysis to generate a composite index, with sensitivity analyses conducted by varying the included indicators. Poisson regression with interrupted time-series analysis was conducted to examine monthly age and gender-standardised mortality rates in the Irish population, ages ≥35 years, stratified by tertiles of SES indicators. All models were adjusted for time trend, season, influenza, and smoking prevalence.

Results: Post-ban mortality reductions by structural SES indicators were concentrated in the most deprived tertile for all causes of death, while reductions by material SES indicators were more equitable across SES tertiles. The composite indices mirrored the results of the discrete indicators, demonstrating that post-ban mortality decreases were either greater or similar in the most deprived when compared to the least deprived for all causes of death.

Conclusions: Overall findings indicated that the national Irish smoking ban reduced inequalities in smoking-related mortality. Due to the higher rates of smoking-related mortality in the most deprived group, even equitable reductions across SES tertiles resulted in decreases in inequalities. The choice of SES indicator was influential in the measurement of effects, underscoring that a differentiated analytical

approach aided in understanding the complexities in which structural and material factors influence mortality.

4.2. INTRODUCTION

The Republic of Ireland was the first country in the world to implement a national workplace smoking ban on March 29, 2004. The implementation of this comprehensive legislation, including a ban on smoking in restaurants, pubs, and bars, resulted in large immediate decreases in mortality due to ischemic heart disease (IHD), stroke, and chronic obstructive pulmonary disease (COPD) (Stallings-Smith et al., 2013). Previous studies have shown that mortality rates for IHD (Avendano et al., 2006), stroke (Addo et al., 2012), and COPD (Prescott et al., 2003) are greater in persons of low socioeconomic status (SES). However, the impact of the national Irish smoking ban on inequalities in mortality is unknown.

A recent study on the global burden of disease demonstrated that tobacco smoking including secondhand smoke was the leading risk factor for death and disability-adjusted life years in North America and Western Europe and the second leading risk factor globally, with a global mortality burden of 6.3 million deaths (Lim et al., 2012). Echoing the fundamental research of Geoffrey Rose (1985), it was suggested that population-wide public health policies can most effectively save lives by tackling the major risk factors of disease burden, where minimal decreases in exposure can result in considerable health improvements (Lim et al., 2012). However, when addressing population-wide risk factors, the impact on inequalities should also be considered. Most inequalities in mortality are attributable to non-communicable diseases, with the highest rates occurring in the most deprived groups; importantly, these inequalities in non-communicable diseases are largely driven by the social gradient in smoking (Di Cesare et al., 2013). In Ireland, manual occupation groups and unemployed groups have the greatest prevalence of active smoking in the population (Layte & Whelan, 2009; OTC, 2012); these groups also have greater rates of mortality due to cardiovascular and respiratory diseases ("Balanda, K.P. & Wilde, J. for the Institute of Public Health in Ireland," 2001).

When assessing the effects of a population-wide intervention, such as a smoking ban policy, it is important to consider that the leftward shift in the exposure distribution may not be equivalent among population subgroups as other factors will determine variability in risk (Rose, 1985) and impact the existing social patterning of health (Macintyre, 1994). Since most risk factors for smoking and smoking-related diseases are modified by SES, it is plausible that the resulting health effects following the implementation of a comprehensive smoking ban policy will be distributed differently across SES groups.

Few epidemiological studies of smoking ban effects in other countries have examined post-ban differentials by SES and findings have been inconsistent (Barnett et al., 2009; Cesaroni et al., 2008; Mackay et al., 2010a; Mackay et al., 2013; Millett et al., 2013). Of these studies, only two have included mortality events in analyses of an adult population, with respective outcomes of acute coronary events and stroke, and have yielded contradictory findings (Cesaroni et al., 2008; Mackay et al., 2013). Therefore, the impacts of smoking ban policies on inequalities in mortality remain to be elucidated. No study has yet examined post-ban respiratory effects by SES in an adult population.

SES indicators represent aspects of structural power, such as education and occupation which influence social standing, and access to material resources, such as secure housing and car access, that provide opportunities for a healthy life (Lynch & Kaplan, 2000). However, the influence of these indicators can change over time and interact through different mechanisms to influence health status and, subsequently, mortality (Link & Phelan, 1995). Many research studies approximate SES with only one indicator, which fails to capture the complexities of how structural and material factors discretely influence living and working conditions. Previous research has shown that different indicators and classifications of SES, though generally resulting in consistent associations with health, are not always equivalent measures (Abramson et al., 1982; Davey Smith et al., 1998a; Macintyre et al., 2001;

Macintyre et al., 2003). Therefore, the use of multiple indicators to approximate SES can aid in elucidating how structural and material factors discretely influence associations with health outcomes.

No study has yet examined the influence of discrete SES indicators on the measurement of post-smoking ban mortality effects. This study expands previous work which demonstrated immediate mortality reductions in IHD, stroke, and COPD mortality following implementation of the national Irish smoking ban (Stallings-Smith et al., 2013) and includes an extended analysis with mortality data for the years 2008-2010 to examine monthly effects by discrete SES indicators and a composite index.

4.3. METHODS

Data Sources for the Republic of Ireland

National mortality data were obtained from the Central Statistics Office (CSO) Ireland for the study period of 2000-2010. Mortality data were coded according to the *International Classification of Diseases, 9th Revision* (ICD-9) from 2000-2006 and according to the *International Classification of Diseases, 10th Revision* (ICD-10) from 2007-2010. Analyses were conducted for the following smoking-related causes of death: IHD (410-414, 429.2/I20-I25), stroke (430-438/I60-I69), and COPD (490-492, 494-496/J40-J44, J47).

To calculate the age and gender-specific population offset for use in statistical modelling and for information on area-level SES indicators, census data for the years 2002 and 2006 were obtained from the CSO Ireland (CSO, 2007). To enable adjustment for potential confounding due to epidemics of influenza, weekly influenza-like illness (ILI) surveillance data were obtained from the Irish Health Protection Surveillance Centre for the influenza seasons (October-May) of 2000-2001 to 2010-2011 (HPSC, 2011a). ILI activity for the influenza season of 1999-2000 was approximated using published data from the European Influenza Surveillance Scheme (Mantey & Mosnier, 2000). Monthly smoking prevalence data from a nationally representative computer-assisted telephone survey of 1,000 persons per month, ages ≥15 years, were obtained from the Ireland Office of Tobacco Control (OTC) for the months of July 2002-December 2010 ("Irish National Tobacco Control Office,"). A linear regression fitted to OTC data was used to approximate smoking prevalence for 2000-2001.

SES Indicators

There are 34 local authorities in Ireland, composed of 29 county councils and five city councils. Based upon previous research (Cesaroni et al., 2003; Krieger et al., 1997; Michelozzi et al., 1999; Tello et al., 2005) and data availability at the level of local authority area, the following structural SES indicators were selected for analyses: education, occupation, foreign nationality, and family composition, along with three material SES indicators: unemployment, housing tenure, and car access. As income data were not available for every local authority area, housing tenure and car access were used to approximate material resources (Davey Smith & Egger, 1992; Davies et al., 1997).

The Irish census offered several response groups for each of the SES indicators. As a result, it was necessary to collapse the indicator groupings for further analysis. For five of the seven SES indicators, identifying deprivation boundaries was straightforward as the divisions for the collapsed groupings were intuitively binary. The result was that persons either fell in one group or the other. Specifically, persons could either be Irish/UK nationals or non-Irish/non-UK nationals, with a family composition of ≥5 persons or a family composition of ≤4 persons, employed or unemployed, living in owned housing or rented/free housing, with car access or no car access.

However, identifying the appropriate groupings for the education and occupation indicators was more complex. For example, the census question regarding educational status provided 14 response possibilities, which needed to be collapsed into meaningful groups for analyses. In order to designate the boundaries for these groupings, correlations between the educational non-response category and all other educational response categories were assessed using Spearman rank order correlation tests, which resulted in three pooled educational groups of low, intermediate, and high. Analyses to determine the response groupings for the occupation indicator were similarly conducted by assessing correlations between the 'all others gainfully occupied and unknown' category and each of the other occupational response categories.

Census categories capturing non-response were ≤5% in each local authority area for all SES indicators except education (range: 3-9%). Since the non-response group for educational status was correlated with the no education group, non-response frequencies were combined with no education and primary education in the low education grouping. This was consistent with previous research demonstrating that survey non-response and educational item non-response are associated with socioeconomic disadvantage (Chittleborough et al., 2008; Dengler et al., 1997; Ekholm et al., 2010; Volken, 2013).

For occupation, there was no discrete group for non-response as the census variable was comprised of all others gainfully occupied and unknown. The frequency of this group was inflated (range: 13-29%), a phenomenon which has been attributed to the introduction of a new filter question in the 2002 census form which may have resulted in respondents' exclusion of questions relating to occupational status (Breathnach, 2007). However, the non-response group was not correlated with any manual occupation groups and was thus excluded from frequency calculations of deprivation. The unskilled, semi-skilled, and skilled manual occupation groups were highly correlated, indicating that the appropriate occupational grouping was in the binary form of manual versus non-manual. The suitability of this grouping is consistent with previous evidence from Ireland demonstrating a distinct difference in smoking prevalence between manual and non-manual occupations, with manual workers being more than twice as likely to smoke daily as their non-manual counterparts (Layte & Whelan, 2009).

Statistical Analyses

Census data for each of the SES indicator groupings from the years 2002 and 2006 were linearly interpolated to determine the remaining values for 2000-2010. Frequencies of each SES indicator were then calculated for the 34 local authority areas in Ireland for the full study period. Consistent with previous research (Tello et al., 2005), only the SES indicator groupings representing conditions of deprivation were selected for further analyses. Descriptive analyses were conducted to confirm that each SES indicator had sufficient variability to detect an effect in analyses of the mortality data. Spearman rank order correlation tests were then conducted to explore relationships between each of the SES indicators.

A baseline principal component analysis (PCA) with varimax rotation, the most efficient method for obtaining simple structure (Kline, 1994), was conducted to jointly analyse the seven, discrete SES indicators, all expressed as a percentage: low education, manual occupation, non-Irish/non-UK nationality, ≥5 person families, male unemployment, rented/free housing, and no car access. Based upon the Kaiser-Guttman rule (Kaiser, 1992), and confirmed by a scree plot (Kline, 1994), two factors were extracted, explaining 81% of the overall variance. The first factor loaded highly on the education, occupation, foreign nationality, and family composition indicators, characterising a structural factor (Laaksonen et al., 2005; Marmot et al., 2012). The second factor loaded highly on the indicators of unemployment, housing tenure, and car access, characterising a material factor (Laaksonen et al., 2005; Marmot et al., 2012). The algebraic sum of these two factors was used as the composite measure of SES for each local authority (Cesaroni et al., 2003; Michelozzi et al., 1999; Tello et al., 2005).

To determine whether findings from previous mortality analyses over a 2000-2007 study period (Stallings-Smith et al., 2013), were influenced by an extended post-ban follow-up period to the year 2010 inclusive, an interrupted time-series Poisson regression analysis was conducted to analyse weekly age and gender-standardised, cause-specific mortality rates with the additional three years of post-ban mortality data. Results, reported as rate ratios (RR), were comparable to previous analyses, with immediate post-ban reductions detected for IHD, stroke, and COPD (Table 4.1). However, weekly mortality counts were insufficient to allow for additional stratification by SES groups; therefore, all further analyses were conducted with monthly mortality counts.

Table 4.1: Pre- and Post-Smoking Ban Effects in Weekly Mortality Rates†‡, Ages ≥35 years, Republic of Ireland, 2000-2010

	Pre-Ban	**Post-Ban**	
Cause of Death	**Trend Effects**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
Ischemic Heart Disease	0.95 (0.94-0.97)	0.85 (0.77-0.93)	0.99 (0.96-1.02)
Stroke	0.94 (0.92-0.96)	0.71 (0.62-0.80)	1.00 (0.97-1.04)
Chronic Obstructive Pulmonary Disease	0.97 (0.94-0.99)	0.81 (0.69-0.96)	1.00 (0.96-1.05)

†Adjusted for season, influenza, and smoking prevalence
‡Age and gender-standardised according to average census population figures for 2002 and 2006

Each of the area-level SES indicators and the composite index were assigned to IHD, stroke, and COPD deaths in the Irish population by local authority area. The analysis was restricted to mortality events in ages ≥35 years to reflect the population at risk for smoking-related mortality. The distributions for the composite SES index and each of the SES indicators across the 34 local authority areas were divided into tertiles, a categorisation also employed in previous social epidemiology research (Reijneveld et al., 2000; van Lenthe & Mackenbach, 2006). A narrower categorisation of the SES indices was not possible due to insufficient monthly counts by age and gender for each of the mortality causes.

Poisson regression with interrupted time-series analysis was then conducted to examine monthly age and gender-standardised mortality rates for the period of 2000-2010, stratified by tertiles of each SES indicator and the composite index. Methodological details of the Poisson regression analyses and adjustment for potential confounding factors have been reported elsewhere (Stallings-Smith et al., 2013). Briefly, all models were designated to account for the underlying mortality trend, the step change occurring in the month following smoking ban implementation, and the post-ban annual change in trend, with adjustments for season, influenza, and smoking prevalence in all models. Seasonal adjustments were based upon calendar months with winter defined as December-February, spring as March-May, summer as June-August, and autumn as September-November. Periods of high ILI activity were defined as months in which the reported rate of ILI was ≥60/100,000, roughly twice the background rate of ILIs for the Republic of Ireland. Smoking prevalence adjustments were based upon annual means.

All analyses were conducted using SAS version 9.2, with the FACTOR procedure for PCA (SAS, 2013a) and the GLIMMIX procedure for statistical modelling (SAS, 2013b). For the presentation of results, beta coefficients were exponentiated to derive rate ratios (RR).

To test for statistically important differences between effect estimates of SES tertiles, 95% confidence intervals were calculated as: $\left(\hat{Q}_1 - \hat{Q}_2\right) \pm 1.96\sqrt{S\hat{E}_1 \pm S\hat{E}_2}$ and 90% confidence intervals were calculated as $\left(\hat{Q}_1 - \hat{Q}_2\right) \pm 1.645\sqrt{S\hat{E}_1 \pm S\hat{E}_2}$, where $\hat{Q}_1$ and $\hat{Q}_2$ were the estimates for two tertiles (for example, the least and most deprived) and $S\hat{E}_1$ and $S\hat{E}_2$ were their respective standard errors (Zeka et al., 2006).

Sensitivity Analyses

Since education was the only ternary SES indicator and all others were binary, an additional PCA (Sensitivity Analysis 1) was conducted with the inclusion of the high education variable to capture the two tails of the educational distribution, as recommended in previous social research (Tello et al., 2005). For consistency, the high education variable was also assessed in discrete analyses.

Additionally, in previous studies wherein a composite SES index was generated from census data, the unemployment indicator was composed of males only (Cesaroni et al., 2003; Michelozzi et al., 1999). In Ireland, labour force participation is indeed greater for males than that for females (CSO, 2011). However, from 2001-2007, female labour force participation grew from 48% to 55% (CSO, 2011), demonstrating that females were increasingly contributing to the Irish economy during the study period.

Therefore, population unemployment was considered as an additional SES indicator in discrete and composite sensitivity analyses (Sensitivity Analysis 2).

Although an SES indicator capturing foreign nationality was utilised in discrete and composite analyses for consistency with previous social research (Cesaroni et al., 2009; Cesaroni et al., 2006; Cesaroni et al., 2010; Cesaroni et al., 2008; Dove et al., 2010), the population represented by the non-Irish/non-UK nationality indicator was extremely diverse. For example, non-Irish/non-UK nationals were typically younger, with higher educational statuses, and greater labour force participation rates than their Irish/UK counterparts; however, non-Irish/non-UK nationals were also more likely to be working in manual occupations with a frequency of unskilled workers approximately twice that of Irish/UK nationals (CSO, 2008). Therefore, since the foreign nationality indicator did not seem to serve as a clear measure of deprivation in the Irish context, an additional composite sensitivity analysis (Sensitivity Analysis 3) was conducted with the exclusion of the non-Irish/non-UK nationality variable, also substituting population unemployment for male unemployment due to the clearer trends identified in prior discrete analyses.

After examining post-ban effects by both discrete SES indicators and composite SES indices, sensitivity analyses were conducted to test post-ban effects by the structural and material factors that were generated and extracted during prior principal component analyses. These sensitivity analyses were conducted with the separate factors for both the baseline index and Sensitivity Index 3, which was identified as the most appropriate composite index based upon the percentage variance of the individual variables explained by the components (82%). The separate factors were assigned to mortality events by local authority areas, and the distribution was divided into tertiles for the subsequent interrupted time-series Poisson regression analysis.

As a final sensitivity analysis, previously published Irish deprivation index scores, comprised of different census indicators than the ones employed in this study, were obtained at the level of the local authority area for the census years 2002 and 2006, and used to approximate SES in the assessment of post-ban mortality effects. These deprivation index scores, calculated by an independent social and economic consultant, were based upon multiple SES indicators including the percentage age-based dependent population, percentage of the population with primary or third-level education, and population unemployment rates (Haase & Pratschke, 2008). Both an absolute deprivation index score, which was measured on a fixed scale across census years, and a relative deprivation index score, which was rescaled for each census wave, were employed in sensitivity analyses. These analyses were conducted by linearly interpolating the deprivation index scores for the remaining years of the 2000-2010 study period, assigning the new index to mortality events by local authority areas, and dividing the distribution into tertiles for the subsequent interrupted time-series Poisson regression analysis.

4.4. RESULTS

Table 4.2 displays the descriptive statistics for each of the SES indicators across the 34 local authority areas. The coefficients of variation demonstrated that the indicator for non-Irish/non-UK nationality exhibited the greatest variability and the indicator for manual occupation exhibited the least variability. As seen in Table 4.3, the Spearman correlation coefficients highlighted the complex relationships between SES indicators. For example, foreign status as a non-Irish/non-UK national was inversely correlated with all indicators except for a weakly positive correlation with population unemployment (0.10) and a moderately positive correlation with rented/free housing tenure (0.41). In turn, rented/free housing tenure was positively correlated with both male (0.56) and population unemployment (0.61) as well as with having no car access (0.60).

The baseline PCA yielded two factors explaining 81% of the overall variance. The principal component rotated matrix shown in Table 4.4 confirmed that the results of the principal component sensitivity analyses were comparable to the baseline PCA in the number of factors identified for extraction and the clear division between the structural and material aspects of SES represented by the factor loadings. The proportion of the overall variance explained by the factors was also similar across all composite indices with Sensitivity Analyses 1-3 respectively explaining 81%, 80%, and 82% of the overall variance.

Consistent with the results of the Spearman correlation matrix, the high education and foreign nationality indicators contributed negative values to the composite indices while all other SES indicators contributed positive values. Although the structural factor was the first to be generated and extracted in the baseline PCA, Sensitivity Analysis 1, and Sensitivity Analysis 2, the material factor was the primary component extracted in Sensitivity Analysis 3. This demonstrated that the inclusion of the population unemployment variable and exclusion of the foreign nationality variable resulted in a shift, wherein more of the variance was explained by the material component rather than the structural component.

From 2000-2010, there were 99,466 total deaths due to IHD (n=60,071), stroke (n=24,203), and COPD (n=15,192) in the Irish population, ages ≥35 years. Seasonal variation was observed, with the largest number of mortality events occurring in winter. Increased ILI activity was detected during eight periods, with the most extended increase occurring for approximately three months of the 2009-2010 influenza season. Smoking prevalence remained relatively stable with an absolute, unadjusted decline of 2% over the study period.

Table 4.5 shows that pre-ban trend effects in monthly mortality were observed for IHD and stroke, but not for COPD. Likewise, immediate post-ban reductions in the month following smoking ban implementation were observed for IHD (RR=0.87; 95% CI: 0.79-0.97) and stroke (RR=0.73; 95% CI: 0.64-0.84), but were only indicative for COPD as the confidence intervals were wide (RR=0.86; 95% CI: 0.70-1.07). Consistent with previously published analyses over a 2000-2007 study period, no post-ban annual trend effects were detected for any causes of death (Table 4.5). Therefore, only SES differentials in immediate post-ban mortality effects are reported for the remainder of the study.

Table 4.2: Descriptive Statistics of Area-Level Socioeconomic Indicators, Republic of Ireland, 2000-2010

Socioeconomic Indicators	**Mean (S.D.) (%)**	**Median Value (%)**	**Coefficient of Variation (%)**	**1st and 2nd Tertile Cutoff Value (%)**	**2nd and 3rd Tertile Cutoff Value (%)**
Low Education	24.3 (5.3)	24.3	21.8	22.0	26.6
High Education*	25.8 (7.1)	24.5	27.5	22.1	27.3
Manual Occupation	35.9 (4.9)	36.6	13.6	34.7	38.0
Non-Irish/Non-UK Nationality	5.8 (3.4)	5.2	58.6	3.9	6.6
≥5 Person Families	18.3 (4.2)	18.3	22.9	16.3	20.3
Male Unemployment	5.5 (1.6)	5.2	29.1	4.7	5.8
Population Unemployment*	4.5 (1.1)	4.3	24.4	4.0	4.7
Rented/Free Housing	22.3 (7.1)	20.4	31.8	18.7	21.6
No Car Access	18.9 (7.1)	16.6	37.5	15.3	18.5

*For sensitivity analyses

Table 4.3: Spearman Correlation Coefficient Matrix for Area-Level Socioeconomic Indicators, Republic of Ireland, 2000-2010

Socioeconomic Indicators	Low Education	High Education*	Manual Occupation	Non-Irish/UK Nationality	≥5 Person Families	Male Unemployment	Population Unemployment*	Rented/Free Housing	No Car Access
Low Education	1.00								
High Education*	-0.85	1.00							
Manual Occupation	0.64	-0.82	1.00						
Non-Irish/UK Nationality	-0.56	0.72	-0.52	1.00					
≥5 Person Families	0.58	-0.66	0.42	-0.82	1.00				
Male Unemployment	0.54	-0.35	0.30	-0.10	-0.02	1.00			
Population Unemployment*	0.42	-0.24	0.26	0.10	-0.19	0.94	1.00		
Rented/Free Housing	-0.03	0.21	-0.25	0.41	-0.53	0.56	0.61	1.00	
No Car Access	0.63	-0.41	0.17	-0.10	0.07	0.78	0.70	0.60	1.00

*For sensitivity analyses

Table 4.4: Principal Component Rotated Matrix for Composite Socioeconomic Indices, Republic of Ireland, 2000-2010

	Baseline Analysis		Sensitivity Analysis 1†		Sensitivity Analysis 2‡		Sensitivity Analysis 3§	
Socioeconomic Indicators	**Factor 1**	**Factor 2**	**Factor 1**	**Factor 2**	**Factor 1**	**Factor 2**	**Factor 1**	**Factor 2**
Low Education	0.85	–	0.81	–	0.88	–	–	0.91
High Education	–	–	-0.92	–	–	–	–	–
Manual Occupation	0.75	–	0.79	–	0.77	–	–	0.83
Non-Irish/Non-UK Nationality	-0.84	–	-0.84	–	-0.81	–	–	–
≥5 Person Families	0.82	–	0.81	–	0.80	–	–	0.74
Male Unemployment	–	0.87	–	0.89	–	–	–	–
Population Unemployment	–	–	–	–	–	0.87	0.84	–
Rented/Free Housing	–	0.85	–	0.80	–	0.86	0.90	–
No Car Access	–	0.95	–	0.93	–	0.93	0.94	–

†Including High Education
‡Substituting Male Unemployment with Population Unemployment
§Substituting Male Unemployment with Population Unemployment and Excluding Nationality

Table 4.5: Pre- and Post-Smoking Ban Effects in Monthly Mortality Rates†‡, Ages ≥35 years, Republic of Ireland, 2000-2010

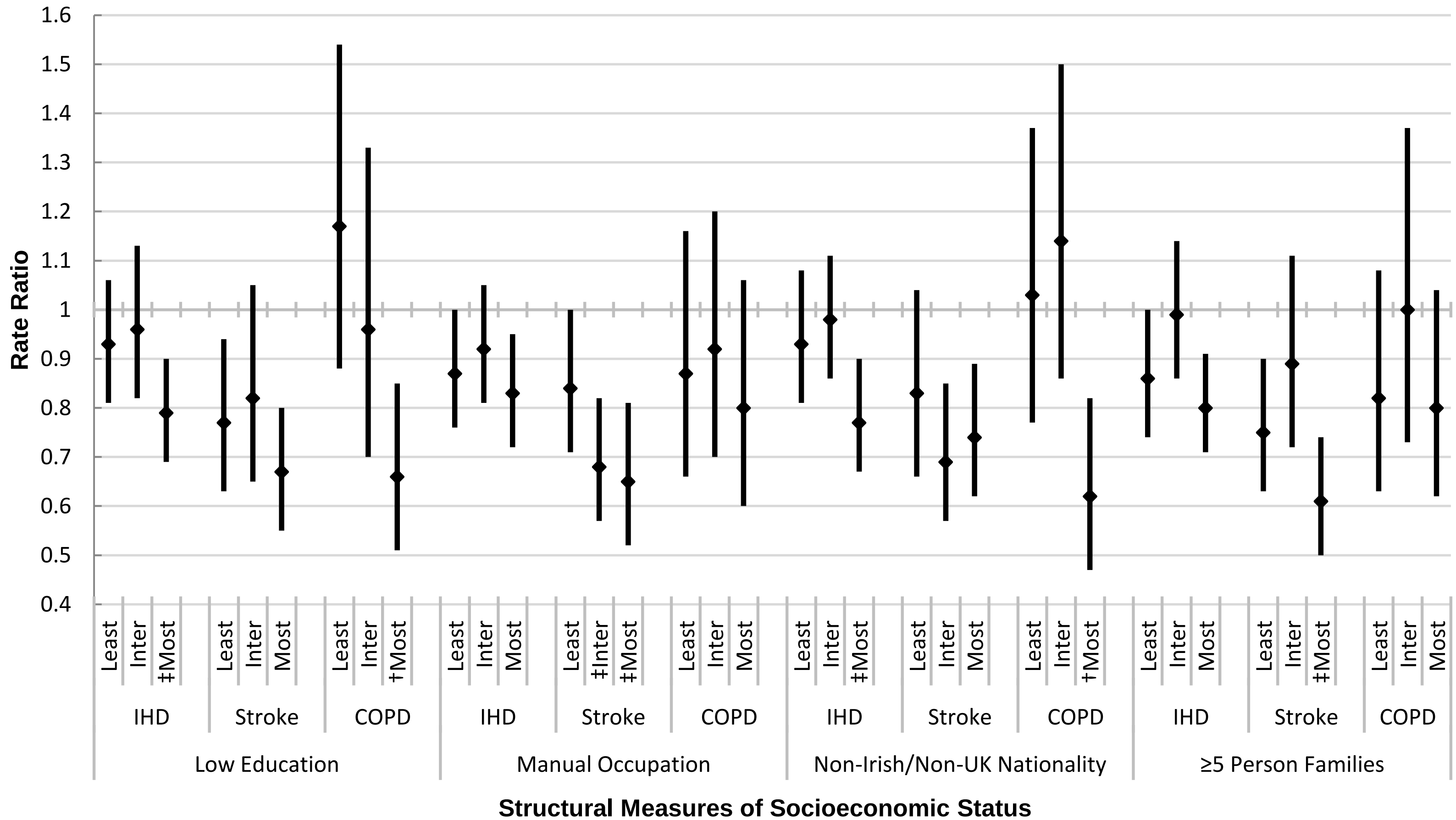
	Pre-Ban	Post-Ban	
Cause of Death	**Trend Effects**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**
Ischemic Heart Disease	0.96 (0.94-0.98)	0.87 (0.79-0.97)	0.99 (0.96-1.02)
Stroke	0.94 (0.92-0.97)	0.73 (0.64-0.84)	1.00 (0.96-1.04)
Chronic Obstructive Pulmonary Disease	0.97 (0.94-1.01)	0.86 (0.70-1.07)	1.00 (0.94-1.06)

†Adjusted for season, influenza, and smoking prevalence
‡Age and gender-standardised according to average census population figures for 2002 and 2006

Post-ban mortality effects by structural SES indicators are shown in Figure 4.1. Overall, effects were concentrated in the most deprived tertile across all causes of death, indicating post-ban reductions in smoking-related inequalities. Specifically, effects by low education were exhibited only in the most deprived tertile for IHD and COPD, and in both the least and most deprived tertiles for stroke with statistically similar effects. When examined by manual occupation and families of ≥5 persons, IHD and stroke effects were strongest in the most deprived tertiles, with no effects observed for COPD. Post-ban IHD and COPD effects were only detected in local authority areas of Ireland with the greatest frequency of non-Irish/non-UK nationals, with statistically similar stroke effects detected in both the intermediate and most deprived groups.

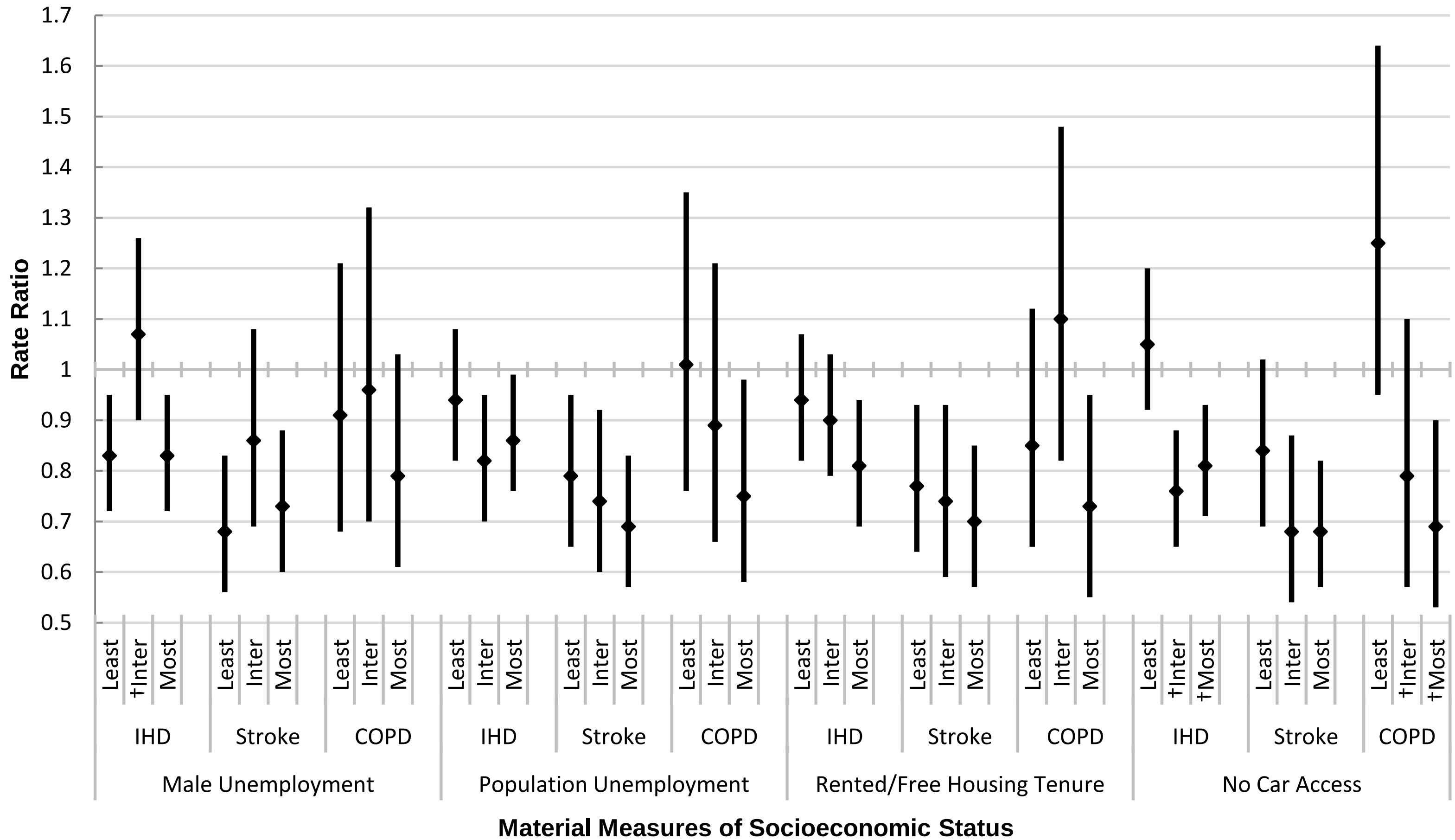
Post-ban immediate mortality effects by material SES indicators are shown in Figure 4.2. The overall trend indicated equitable mortality reductions across SES tertiles, with statistically similar effects detected by male unemployment, population unemployment, and rented/free housing tenure. When ban effects were examined by the no car access indicator, reductions in inequalities were detected, with greater effects observed in the intermediate and most deprived tertiles as compared to the least deprived tertile. Male unemployment did not yield effects consistent with that of the other material measures. However, analyses by population unemployment yielded a clearer trend, also mirroring results by rented/free housing tenure.

Figure 4.1: Immediate Post-Smoking Ban Mortality Effects by Structural Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010*



*'Least' refers to the least deprived tertile, 'Inter' to the intermediate tertile, and 'Most' to the most deprived tertile
†Significantly different from least deprived tertile at 95% confidence level
‡Significantly different from least deprived tertile at 90% confidence level

Figure 4.2: Immediate Post-Smoking Ban Mortality Effects by Material Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010*

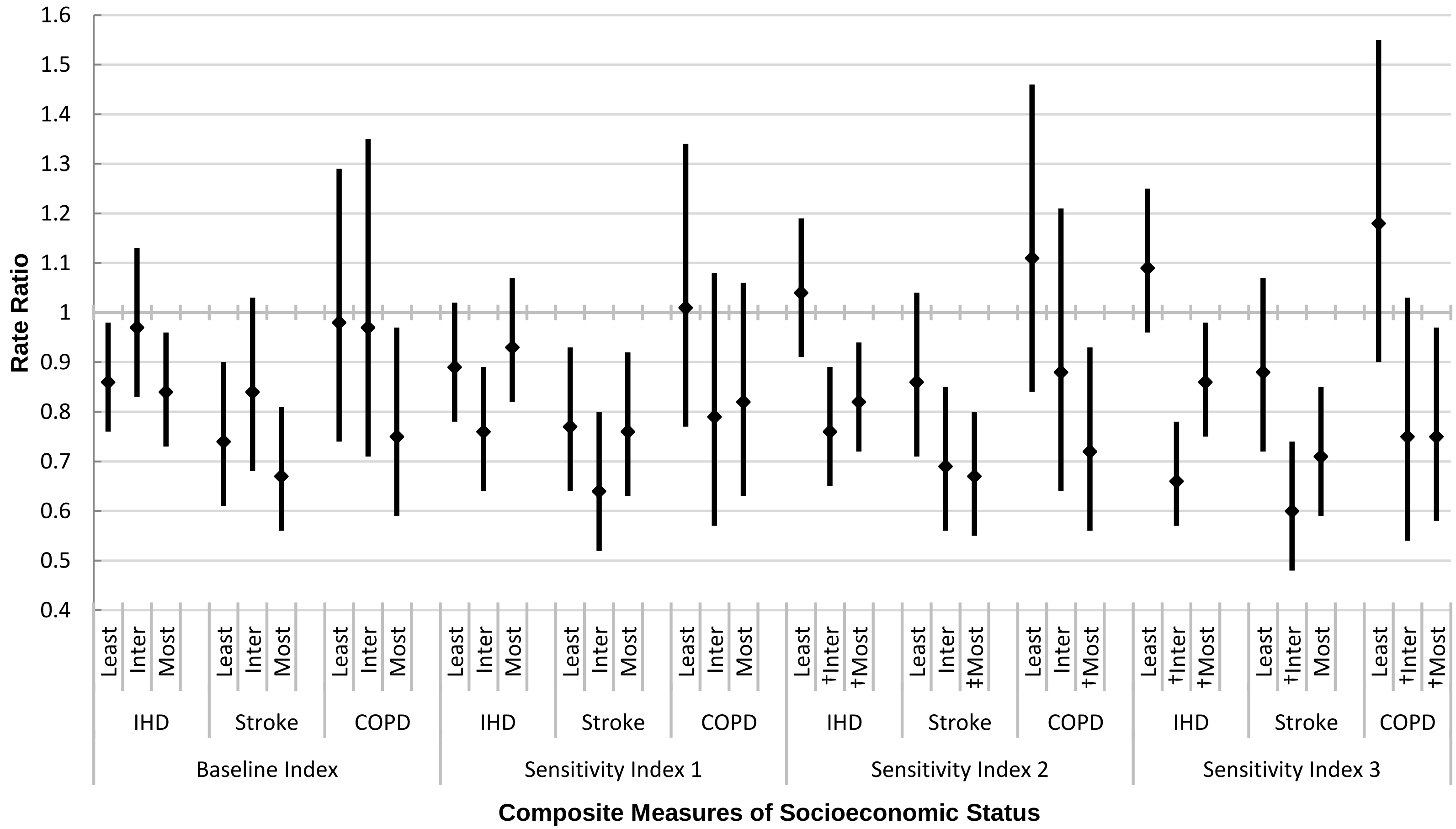


*'Least' refers to the least deprived tertile, 'Inter' to the intermediate tertile, and 'Most' to the most deprived tertile
†Significantly different from least deprived tertile at 95% confidence level
‡Significantly different from least deprived tertile at 90% confidence level

Post-ban effects by the baseline and sensitivity composite indices are shown in Figure 4.3. IHD and COPD effects were attenuated in the composite index when compared to effects by discrete SES indicators, but composite stroke effects generally fell within the confidence limits of the discrete effects. Both the baseline index and Sensitivity Analysis 1 indicated equitable mortality reductions across SES tertiles, consistent with the overall effects detected by the discrete, material SES indicators. However, the results of Sensitivity Analyses 2 and 3 demonstrated reductions in inequalities, with statistically greater effects detected in the intermediate and most deprived tertiles when compared to the least deprived tertile, closely mirroring overall effects detected by the discrete, structural SES indicators.

Figure 4.4 displays immediate post-ban effects by the separate factors extracted in the principal component analysis for both the baseline index and for Sensitivity Index 3. The first factor extracted for the baseline index was characterised by the structural SES indicators, with loadings on low education, manual occupation, non-Irish/non-UK nationality, and ≥5 person families. These results mirrored those observed by the discrete structural indicators (Figure 4.1), with greater effects exhibited in the most deprived and intermediate tertiles across all causes of death, indicating reductions in inequalities. Factor 2 of the baseline index was characterized by the material SES indicators, with loadings on male unemployment, rented/free housing tenure, and no car access. However, effects seemed largely driven by the no car access variable (Figure 4.2), coinciding with its strong factor loading of 0.95 (Table 4.4). These findings demonstrated post-ban mortality reductions that were concentrated in both the most deprived and intermediate tertiles, which were statistically stronger for IHD and COPD, and statistically similar across SES tertiles for stroke.

Figure 4.3: Immediate Post-Smoking Ban Mortality Effects by Composite Measures§ of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010*



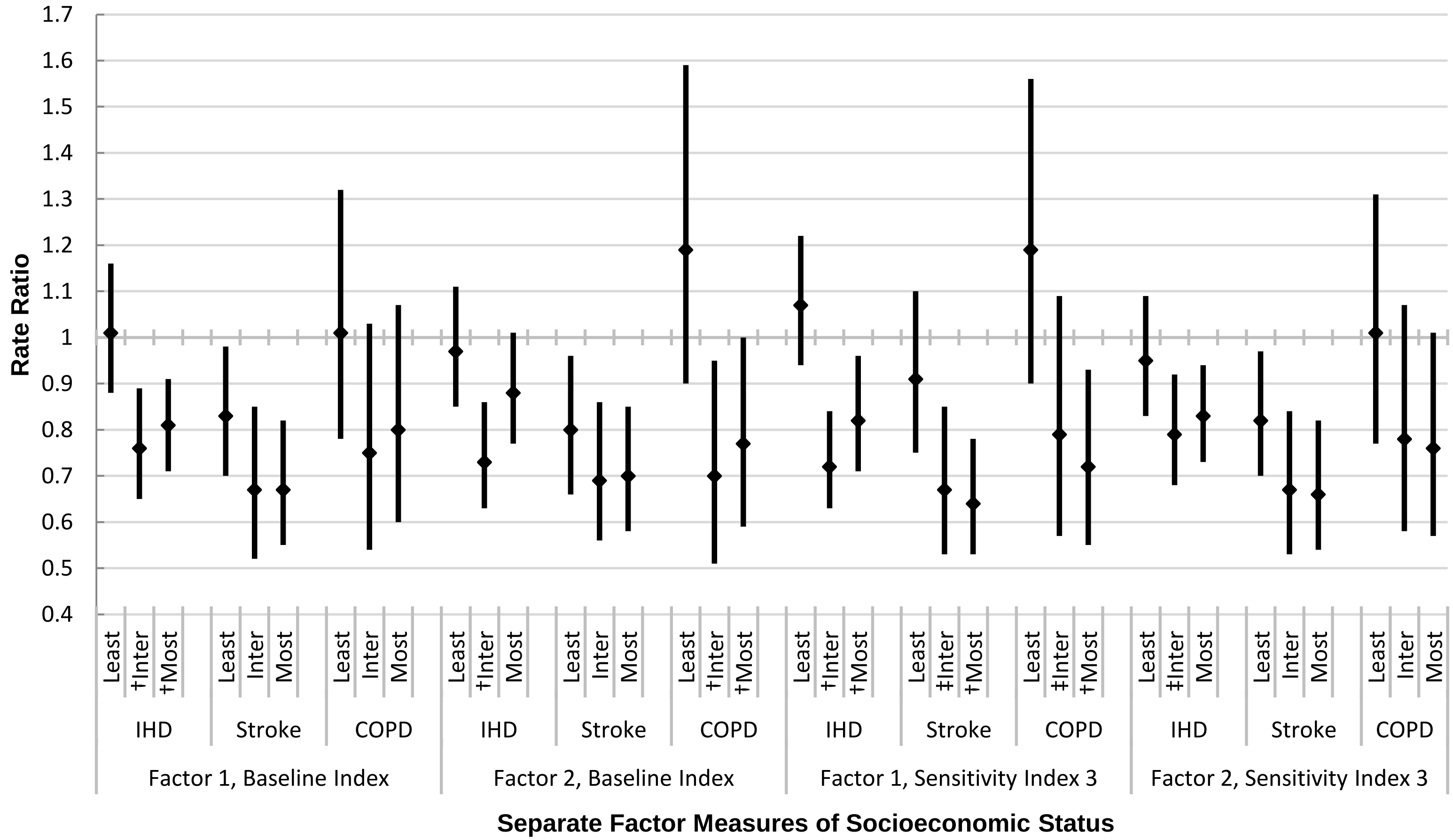
§Baseline Index includes Low Education, Manual Occupation, Non-Irish/Non-UK Nationality, ≥5 Person Families, Male Unemployment, Rented/Free Housing Tenure, and No Car Access. Sensitivity Index 1 includes Baseline Index and High Education. Sensitivity Index 2 substitutes Male Unemployment with Population Unemployment. Sensitivity Index 3 substitutes Male Unemployment with Population Unemployment and excludes Nationality.

*'Least' refers to the least deprived tertile, 'Inter' to the intermediate tertile, and 'Most' to the most deprived tertile

†Significantly different from least deprived tertile at 95% confidence level

‡Significantly different from least deprived tertile at 90% confidence level

Figure 4.4: Immediate Post-Smoking Ban Mortality Effects by Separate Factor Measures of Socioeconomic Status, Ages ≥35 years, Republic of Ireland, 2000-2010*§

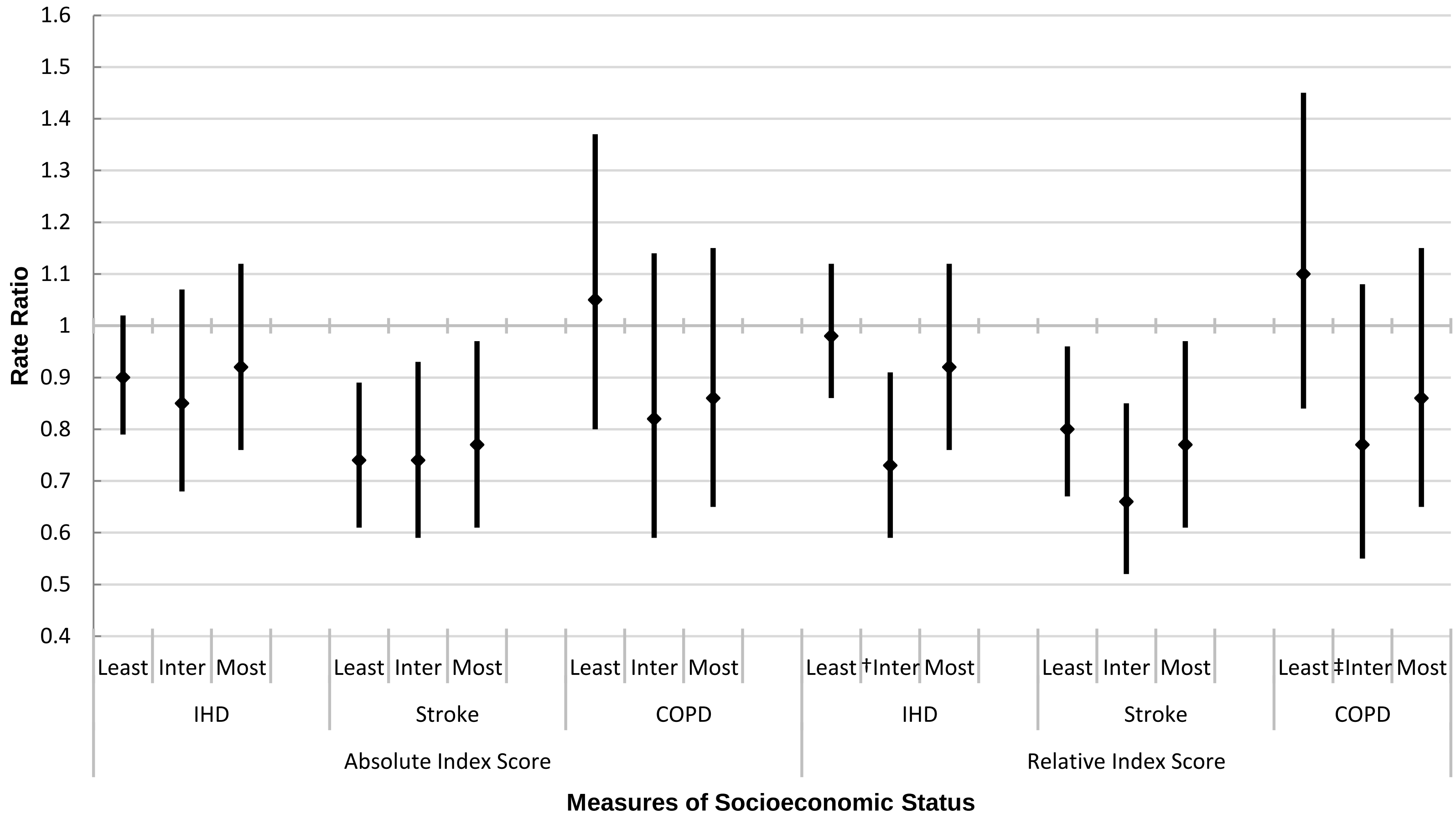


*'Least' refers to the least deprived tertile, 'Inter' to the intermediate tertile, and 'Most' to the most deprived tertile
§Factor 1 of the Baseline Index loaded highly on the structural SES indicators, Factor 2 of the Baseline Index loaded highly on the material SES indicators, Factor 1 of Sensitivity Index 3 loaded highly on the material SES indicators, and Factor 2 of Sensitivity Index 3 loaded highly on the structural SES indicators
†Significantly different from least deprived tertile at 95% confidence level
‡Significantly different from least deprived tertile at 90% confidence level

In contrast to the baseline index, Factor 1 of Sensitivity Index 3 was characterized by the material SES indicators rather than the structural SES indicators, with loadings on population unemployment, rented/free housing tenure, and no car access. Thus, Factor 2 of Sensitivity Index 3 was characterized by the structural SES indicators with loadings on low education, manual occupation, and ≥5 person families. When these factor-specific post-ban effects were compared to the overall effects for Sensitivity Index 3, as represented in Figure 4.3, the material factor clearly functioned as the driver of the overall composite index, with statistically stronger effects observed in the most deprived and intermediate tertiles as compared to the least deprived tertile.

The post-ban effects resulting from the sensitivity analyses by the absolute and relative deprivation index scores are displayed in Figure 4.5. For the absolute deprivation index scores, post-ban effects were equitable across SES tertiles for all causes of death. For the relative deprivation index scores, post-ban effects were concentrated in the intermediate tertile, with statistically stronger effects for IHD and COPD, but equitable effects across tertiles for stroke. These results were similar to those detected in this study for Sensitivity Index 3 (Figure 4.3).

Figure 4.5: Immediate Post-Smoking Ban Mortality Effects by Previously Published Deprivation Index Scores[§], Ages ≥35 years, Republic of Ireland, 2000-2010*



[§]Deprivation index scores obtained from a previously published document by Haase and Pratschke, 2008
*'Least' refers to the least deprived tertile, 'Inter' to the intermediate tertile, and 'Most' to the most deprived tertile
[†]Significantly different from least deprived tertile at 95% confidence level
[‡]Significantly different from least deprived tertile at 90% confidence level

4.5. DISCUSSION

Overall findings indicate that in the month following the implementation of the national Irish smoking ban, inequalities in smoking-related mortality were reduced. Since the observed post-ban mortality decreases were either greater or similar in the most deprived tertile when compared to the least deprived tertile, reductions in inequalities occurred due to the existing higher rates of smoking-related mortality in the most deprived SES group. Although the choice of SES indicator influenced the measurement of effects, results were broadly consistent across discrete indicators and composite indices, demonstrating that the Irish national smoking ban did not widen inequalities and, in some cases, largely reduced inequalities in smoking-related mortality.

As this was the first study to assess post-smoking ban effects by discrete SES indicators, direct comparisons cannot be made with any other studies. The findings of this study demonstrated that post-ban mortality effects by the structural indicators of low education, manual occupation, and ≥5-person families were detected solely or most strongly in the most deprived. However, mortality effects by the frequency of non-Irish/non-UK nationals were more difficult to interpret due to the varied composition of the population that was represented. The discrete mortality analyses demonstrated that benefits were concentrated in local authority areas with the highest frequency of non-Irish/non-UK nationals, which was consistent with effects by all other structural deprivation indicators. Nevertheless, a direct conclusion cannot be deduced as the nationality indicator did not serve as a clear measure of deprivation in the Irish context. Exploratory analyses demonstrated that the high education indicator was also not a clear discrete SES measure as indicated by its inconsistency of IHD effects compared with the other structural measures and its failure to capture the large COPD reductions detected by the low education indicator.

In comparison with post-ban mortality effects by structural SES indicators, effects by material SES indicators did not exhibit a clear trend for IHD, with effects detected in both the most deprived and either the intermediate or least deprived tertiles by male unemployment, population unemployment, and no car access. In contrast, when examined by rented/free housing, IHD effects were only detected in the most deprived tertile and stroke effects were detected in all three tertiles, with the strongest effects in the most deprived. Stroke effects by material SES indicators were more comparable to effects by structural SES indicators, with effects generally observed across all tertiles with the greatest magnitude of effects in the most deprived. When effects were observed for COPD, mortality reductions were detected only in the most deprived tertile. However, mortality reductions were either greater or similar in the more deprived tertiles when compared to the least deprived tertile, once again verifying that the implementation of the national Irish smoking ban reduced existing smoking-related inequalities in mortality.

The contextual applicability of the structural and material indicators was confirmed by the results of their combined assessment in the PCA, yielding two clearly divisible components. One factor characterised the structural aspects of SES, with high loadings on education, occupation, foreign nationality, and family composition. This is consistent with what is previously known in that education and occupation are important in determining social status and social identity (Laaksonen et al., 2005; Marmot et al., 2012). There is also an occupational gradient in smoking prevalence that is consistent with the social gradient in mortality, attributable to the earlier age of beginning smoking and lower rates of cessation among lower SES groups (Jarvis & Wardle, 2006). In addition to the social gradient in smoking prevalence, evidence has also revealed a gradient in nicotine intake, with smokers of lower SES smoking more cigarettes and inhaling each cigarette more intensively than affluent smokers (Bobak et al., 2000; Jarvis & Wardle, 2006; Siahpush et al., 2006b). This higher intake results in a stronger physical addiction to nicotine, making it more difficult for those of low SES to cease smoking even when exhibiting the psychological intent to quit (Bobak et al., 2000; Jarvis & Wardle, 2006).

Furthermore, family composition and foreign nationality may also function as structural determinants of social standing. Large families, defined as families with three or more children, are associated with poverty, and resources become increasingly diluted as the number of children increases (Bradshaw et al., 2006). This concept becomes linked with foreign nationality through the higher fertility rates of non-European Union (EU) migrants (Lunn & Fahey, 2011; Sobotka, 2008). Additional data for Europe indicate that migrants from outside the EU have greater rates of unemployment when compared to EU migrants or native country citizens (Marmot et al., 2012) and migrants from any country are more vulnerable to social exclusion (Kabir et al., 2008; Shaw et al., 2006). As the 2002 Irish census did not differentiate between EU and non-EU migrants, it was not possible to distinguish effects between these groups in this study. Future research from other countries may be able to further elucidate post-ban mortality effects by foreign nationality, particularly if separate data are available for EU and non-EU migrants.

The other factor identified through PCA characterised the material aspects of SES, with high loadings on unemployment, housing tenure, and car access. These concepts are closely associated in that unemployed persons are more likely to live in rented housing and be without car access when compared to their employed counterparts (Bartley et al., 1999). Job insecurity is also associated with cardiovascular disease and with the risk factors for cardiovascular disease (WHO, 2003), which can result in increased risk of mortality.

Further to this, persons living in rented housing and persons without car access have higher mortality rates when compared to house owner-occupiers and car owners (Macintyre et al., 1998). Potential explanations are that living in badly maintained rented housing can result in exposures to environmental risk factors, such as pollution and mould, and psychological risk factors, such as the questionable safety of physical surroundings, while the lack of car access may decrease employability, access to health services, and engagement with social support networks (Macintyre et al., 1998).

Consequently, smoking is heavily employed as a coping mechanism for these stressors (Jarvis & Wardle, 2006; Siahpush et al., 2006a; van Lenthe & Mackenbach, 2006), resulting in increased population exposure to SHS in social and workplace settings. For the most deprived groups, SHS exposure acts concurrently with these other disadvantaged circumstances to yield an increased risk of negative health outcomes. Thus, the large mortality benefits experienced by the most deprived in Ireland indicate that the implementation of the national Irish smoking ban was effective in immediately reducing this harmful exposure to SHS.

When compared to effects by discrete SES indicators, the composite index yielded attenuated effects for IHD and COPD, but effectively captured the magnitude of discrete SES effects for stroke. This finding implies that SES indicators may not always measure inequalities similarly across causes of death. A potential explanation is that IHD, stroke, and COPD are distributed differently across demographic groups. For instance, IHD is responsible for more premature deaths in persons ≤65 years than COPD, which disproportionately affects persons ≥65 years. This results in different risk factor distributions that may be closely associated with SES indicators.

Additionally, the mechanisms by which secondhand smoke exposure can trigger biological responses are disease-specific and may, therefore, result in different effects when the exposure is reduced or removed. For example, exposure to secondhand smoke can result in endothelial dysfunction, leading to ischemic heart disease and increased risk of mortality for those with existing disease; however, the endothelial repair mechanism partially recovers when the exposure is removed, partially accounting for the decreases in ischemic heart disease mortality following smoking ban implementation (Barnoya & Glantz, 2005; Glantz & Parmley, 1995). Though secondhand smoke exposure has been causally linked to ischemic heart disease, limited evidence exists for establishing a causal association between secondhand smoke exposure and stroke or COPD; thus, the evidence is currently classified as suggestive (Eisner et al., 2006; Eisner et al., 2009; He et al., 2012; Oono et al., 2011; "A Report of the

Surgeon General," 2010). As a result, these disease-specific biological response mechanisms have not yet been fully elucidated and present a generative area for further research exploration.

Although Sensitivity Analysis 1 resulted in similar factor loadings to the baseline PCA, the inclusion of the high education variable did not increase the explanatory power for the overall variance and the resulting composite index did not show clear trends in mortality effects. As such, the high education variable did not serve as an appropriate predictor of health inequalities in the Irish context. However, the composite index arising from Sensitivity Analysis 2, substituting population unemployment for male unemployment, provided a clearer trend and coincided more closely with the discrete SES analyses than the baseline PCA. As such, population unemployment was retained in Sensitivity Analysis 3, which also excluded the indicator for foreign nationality, resulting in the most appropriate composite index that accounted for the most overall variance.

These additional analyses demonstrated that the construction of the composite index was quite sensitive to the variables included, most likely due to the contribution of each SES indicator to the frequency of deprivation in a local authority area for a given year, which, in turn, influenced the distribution of mortality events into SES tertiles. Nevertheless, the construction of a composite index through PCA is likely the best approach for identifying SES effects, inherently accounting for both the structural and material aspects of SES, jointly capturing the information represented in discrete analyses, and allowing for identification of the most appropriate combined measure by providing statistically comparable measures of the overall variance explained. However, discrete analyses were a useful first step in understanding how individual indicators served as measures of health inequalities, providing information that is critical when deciding the appropriate indicators to include in the composite index. Such a differentiated, analytical approach was useful in assessing the validity of the overall estimation of effects.

The findings from the sensitivity analyses conducted with the separate factors generated through PCA were consistent with the overall effects resulting from stratification by the discrete structural and material SES indicators. Factor 1 of Sensitivity Index 3, the material factor, was likely the best factor measure of SES in this study, as it was responsible for explaining most of the overall variance of the individual variables, driving the effects demonstrated by the composite index most appropriate to the study population (Sensitivity Index 3). Consistent with previous findings by the discrete and composite SES measures, reductions in inequalities were observed in analyses by each of the separate factor measures.

The sensitivity analyses utilizing previously published absolute and relative deprivation index scores demonstrated overall that smoking ban effects were equitably distributed across SES tertiles. Because the absolute deprivation scores were measured on a fixed scale across years, the majority of local authority areas showed improvement in affluence over time (Haase & Pratschke, 2008). Therefore, the relative index scores, which were rescaled for each census wave, likely served as the more appropriate measures for assessing the mortality effects of smoking ban implementation across local authority areas. The post-ban effects detected by the relative index scores were similar to those exhibited by Sensitivity Index 3, indicating that the national Irish smoking ban was effective in reducing inequalities in smoking-related mortality. However, the previously published deprivation scores were calculated based upon other SES indicators, and, in contrast to Sensitivity Index 3 in this study, did not account for family composition, foreign nationality, housing tenure, or car access.

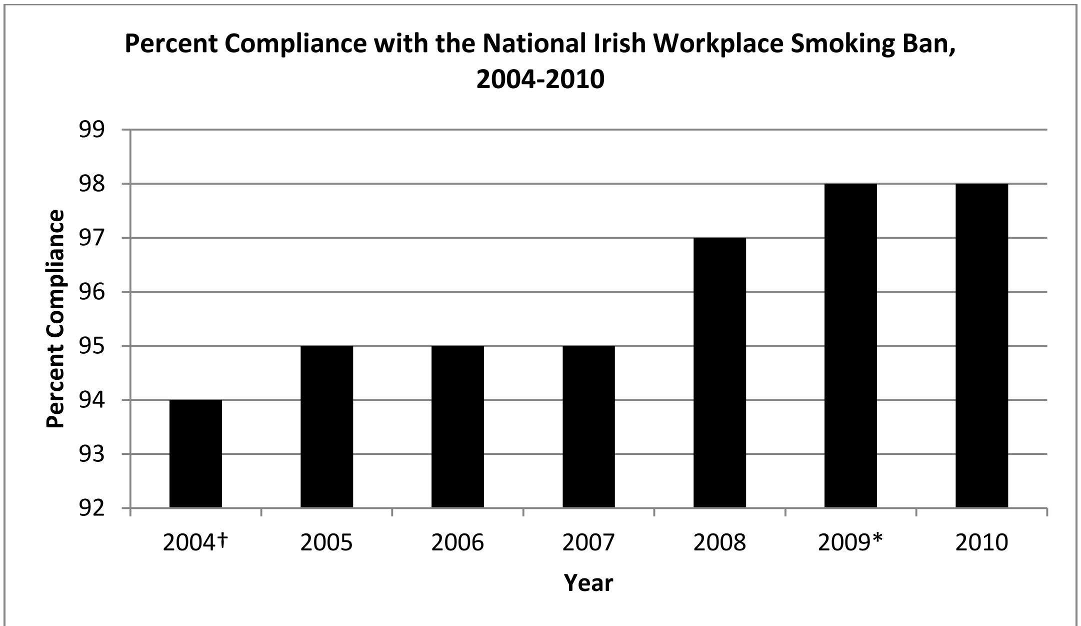
Only two epidemiological studies of smoking ban effects in other countries have examined post-ban mortality differentials by composite SES measurements in an adult population. One study examined rates of acute coronary events, including hospital admissions and out-of-hospital deaths, in the city-wide population of Rome, Italy (Cesaroni et al., 2008). In ages 35-64 years, post-ban reductions were observed in the three lowest SES quintiles, with the largest reductions occurring in the lowest SES quintile, whereas in ages 65-74 years, effects were observed only in the second lowest SES quintile (Cesaroni et al., 2008). Another study examined stroke effects, including hospital admissions and out-of-hospital deaths, in the national population of Scotland, demonstrating that stroke reductions occurred only in ages <60 years and only in the two highest SES quintiles (Mackay et al., 2013). Although a third epidemiological study examined the post-ban SES effect differentials of asthma hospital admissions and deaths in Scotland, the study population was composed of children ≤14 years of age and only five deaths were identified over the study period of 9.75 years (Mackay et al., 2010a); therefore, mortality differentials could not be accurately deduced. Nonetheless, direct comparability of findings from any of the above studies is not possible due to their inclusion of hospital admissions in the estimation of post-ban effects and due to the differing definitions and distributions of SES indicators in Italy, Scotland, and Ireland.

Overall evidence of smoking ban policy impacts on health inequalities is extremely limited. Only two other studies have assessed the health effects of smoking ban policies by SES. A study conducted in Christchurch, New Zealand, assessed the effects of the national smoking ban on hospital admissions due to acute myocardial infarction, defining the SES of each patient according to the New Zealand deprivation index, and found that post-ban effects were only observed for ages 55-74 years in the second highest SES quintile (Barnett et al., 2009). The other study assessed the effects of the national English smoking ban on hospital admissions for childhood asthma in ages ≤14 years, with the SES of each patient defined by the English deprivation index (Millett et al., 2013). Findings indicated that post-ban childhood asthma effects were similar across all SES quintiles (Millett et al., 2013). Since only a handful of studies have examined post-ban differentials by SES and have measured different health outcomes in various cultural contexts, the findings are challenging to generalise. However, this study of the effects of the national Irish smoking ban contributes evidence to indicate that smoking ban policies are associated with reductions in inequalities in smoking-related mortality.

There are two potential mechanisms, likely acting in concurrence, to explain why the observed immediate mortality reductions have resulted in greater benefits for the more disadvantaged population. First, smoking is socially distributed, with a greater prevalence in the more disadvantaged groups, thus resulting in a greater risk of exposure to secondhand smoke (Sims et al., 2012b; Whitlock et al., 1998). Second, there is also a greater prevalence of non-communicable diseases in the more disadvantaged groups, particularly in developed countries (Di Cesare et al., 2013), resulting in a larger at-risk population in which exposure to secondhand smoke could trigger a negative health outcome. These risks were immediately reduced when smoking was banned in workplaces, pubs, and other social environments, plausibly resulting in greater effects for the most disadvantaged groups. The findings of previous analyses provided confirmatory evidence showing that the immediate post-ban mortality reductions were largely due to reductions in exposure to secondhand smoke (Stallings-Smith et al., 2013). The explanations for both of these mechanisms reinforce the fundamental principles for population prevention strategies proposed by Geoffrey Rose (1985), wherein a leftward shift in exposure acting on a large at-risk population produces substantial public health benefits.

As with all routine mortality data, information was not available on individual risk factors such as body mass index, physical activity level, and smoking status; hence, it was not possible to adjust for these in analyses. However, the most current information from the national Survey of Lifestyle, Attitudes, and Nutrition (SLÁN) in Ireland demonstrated that obesity prevalence and physical activity levels remained stable across the 1998, 2002, and 2007 survey waves (HIQA, 2010). All regression models included adjustments for population smoking prevalence. Additionally, previous evidence has shown that cigarette price increases, health warnings on cigarette packaging, and advertising bans in Ireland were not sufficient to explain the large, immediate mortality reductions occurring after implementation of the national workplace smoking ban (Currie et al., 2012). Levels of enforcement can influence the effectiveness of smoking ban policies in yielding health benefits; however, compliance with the national Irish workplace smoking ban was strong (94%) immediately following policy implementation and remained strong over the entire study period (Figure 4.6).

Figure 4.6: Percent Compliance with the National Irish Workplace Smoking Ban, 2004-2010



†Post-ban period of April-December 2004
*Estimated percent compliance due to changes in information technology system (P. Hickey, Senior Environmental Health Officer, Galway, Ireland, personal communication, August 1, 2013)

SES indices were limited to local authority areas, geographic classifications wherein extensive heterogeneity in SES indicators may exist. However, for Ireland the local authority was the smallest area-level classification available within the de-identified mortality data. Likewise, other epidemiologic studies have used the area-level of local authority for analyses of health-related outcomes (Leyland, 2004; Macintyre et al., 2001) and previous research has indicated that the choice of geographical classification, whether at the level of neighbourhood, post code sector, or borough, does not appreciably impact the size of health differences by area deprivation (Reijneveld et al., 2000). Furthermore, the characteristics of an area can provide the context of conditions that influence individual health risks (Lynch & Kaplan, 2000).

However, when aggregate measures are employed as proxies for individual-level indicators in analyses of the association between SES and health outcomes, effect estimates may be biased in either direction as a result of each individual in the area being assigned the same deprivation score; yet, area-level estimates most likely result in the underestimation of individual-level effects (Davey Smith et al., 1998b; Galobardes et al., 2007). Regardless, the direction of the association is not impacted, and therefore, the choice of area or individual-level indicators may not essentially be important when the focus of the study is to assess the socioeconomic gradient in health; nevertheless, the slope of the gradient may be influenced by the choice of the level of SES indicator (Galobardes et al., 2006). In this study, although the smallest area-level measure available was employed to approximate SES, the modifying effect of SES on the association between the smoking ban policy and mortality may have been underestimated.

Strengths of this study include analyses over the longest post-ban period to date, 6.75 years, and further validation of previously reported immediate effects following the implementation of the national Irish workplace smoking ban (Stallings-Smith et al., 2013), indicating persistence of effects over an extended follow-up period. This study was unique in examining the influence of discrete SES indicators on post-ban effect differences in a national population and in providing evidence of SES effect differences in COPD mortality, which has not been reported in any previous studies. In addition, this study contributed to the sparse evidence currently available regarding the SES differences in post-ban IHD and stroke effects, now demonstrating that smoking ban policies have the potential to reduce health inequalities. The Ireland-specific composite SES index generated through PCA was based upon the most relevant census data for the study period, and composite analyses provided corroborative evidence to discrete SES results. The findings of this study have demonstrated the immense public health impacts of smoking ban policies.

The World Health Organization (WHO) has urged for a human rights approach to public health, with precedence given to both improving health and reducing inequalities (Marmot et al., 2012). In order to address the urgent need for evidence, it was strongly recommended that each country begin monitoring health inequalities immediately, using data that are already available (Marmot et al., 2012). Further, it was advised that research on public health policies, in this case a smoking ban, be conducted to assess effects on inequalities with analyses by age, sex, and a minimum of two to three SES indicators (Marmot et al., 2012). In response to these recommendations, and coupled with previously published research, this study has now met all of these criteria and has shown that the national Irish workplace smoking ban resulted in immediate decreases in mortality and corresponding reductions in area-level inequalities.

4.6. CONCLUSION

Overall findings suggest that in the month following the implementation of the national Irish smoking ban, inequalities in smoking-related mortality were reduced. For IHD and COPD, mortality decreases were generally detected either solely or most strongly in the most deprived tertile, while decreases in stroke mortality were generally observed more equitably across SES groups. Regardless, the higher rates of smoking-related mortality in the most deprived group indicate that even equitable reductions across SES tertiles result in decreases in inequalities. The choice of SES indicator was influential in the measurement of effects, underscoring that a differentiated analytical approach was useful for understanding the complexities in which structural and material factors influence mortality.

CHAPTER 5: Discussion

This chapter discusses the principal findings from the three thesis projects and addresses the limitations of each project, particularly in relation to data availability and analytical methods. Strengths of the studies are also highlighted. Finally, the chapter discusses implications for public health research, policy, and practice.

Principal Findings of Thesis Research

The review and narrative synthesis of 37 primary epidemiological studies identified strong evidence of post-ban reductions in cardiovascular morbidity and mortality. This is consistent with the findings of other reviews and meta-analyses assessing single cardiovascular outcomes such as AMI (Glantz, 2008; Lightwood & Glantz, 2009; Lin et al., 2013; Meyers et al., 2009) and ACE (Mackay et al., 2010b). At the time this research commenced, this was the first review to assess post-ban effects in respiratory morbidity and mortality, although a meta-analysis including respiratory morbidity has since been published (Tan & Glantz, 2012). The review and narrative synthesis showed evidence of post-ban respiratory reductions, but far less evidence was available for respiratory outcomes when compared to cardiovascular outcomes. Additionally, no evidence was available for post-ban effects in cerebrovascular mortality. Thus, a recommendation of this review was that researchers should, in addition to assessments of post-ban health effects in cardiovascular outcomes, begin examining cerebrovascular and respiratory effects, thereby addressing the need for stronger evidence of smoking ban policy impacts on these less-studied health outcomes.

The most important finding of this review was the urgent need for evidence of post-smoking ban effects by SES. Since only three studies assessed effect modification by SES in statistical analyses and findings were inconsistent, smoking ban impacts on inequalities still remain uncertain. While focusing on the protection of population health, it is also paramount to consider the most at-risk subgroups of the population by identifying where health inequalities exist and working to reduce the inequalities that have already been documented. The lack of evidence regarding post-smoking ban effects by SES underscores that this critical concern has not been a major focus of the public health research schema to date. This is most likely due to the fact that in the absence of an existing nation-wide index of multiple deprivation, it can be an extremely challenging process to identify appropriate SES variables, to obtain the necessary data, and to generate an applicable composite index for further analyses. This thesis project highlighted the critical need for evidence in assessing smoking ban policy impacts on health inequalities and proposed a brief outline of methods for other public health practitioners to employ in future research.

The second thesis study, an empirical analysis of Irish mortality data from 2000-2007, demonstrated that the national workplace smoking ban was associated with an immediate 13% reduction in all-cause, non-trauma mortality, a 26% reduction in IHD, a 32% reduction in stroke, and a 38% reduction in COPD mortality after adjusting for relevant confounding factors. As this was the first smoking ban study to assess all-cause mortality, comparisons could not be made with any other study. However, an overall post-ban increase was detected in non-smoking related mortality, indicating that the all-cause mortality reductions were driven by smoking-related causes of death.

Since the national Irish smoking ban was enforced in 2004, this study focused only on smoking-related cardiovascular, cerebrovascular, and respiratory causes of death that were likely to demonstrate a change within a short period of time. In contrast, changes due to other smoking-related diseases such as lung cancer would not be expected to occur within the 3.75 post-ban years since the latency period is typically two decades or more, dependent upon the length and type of carcinogenic exposure (Finkelstein, 1991).

Several prior smoking ban studies in other countries have detected significant post-ban decreases in AMI morbidity and mortality (Barone-Adesi et al., 2006; Bonetti et al., 2011; Dove et al., 2010; Herman & Walsh, 2011). In contrast, no AMI mortality reductions were observed in this study of the Republic of Ireland, although large immediate reductions were detected in IHD. The post-ban rate ratios for AMI were in the same direction as those for IHD, although smaller in magnitude and with wider confidence limits, likely due to the smaller number of cause-specific AMI deaths (n=25,979) when compared to IHD (n=44,993). However, these findings were consistent with those of a nationwide study of hospital admissions in the Republic of Ireland reporting a post-ban relative risk of 0.88 (95% CI: 0.70-1.10) for AMI and a post-ban relative risk of 0.81 (95% CI: 0.69-0.95) for ACS , a cause-specific outcome which also included unstable angina (Kent et al., 2012), making it more comparable to the IHD outcome analysed in this study.

This was the first study to analyse post-ban effects in mortality due to stroke and COPD, which demonstrated large immediate reductions following the implementation of the national Irish smoking ban. This indicates that smoking ban policies are indeed effective in reducing these previously unexplored cause-specific outcomes.

Importantly, no gradual trend effects were detected, indicating that post-ban risk differences did not change with a longer follow-up period. It is likely that smoking ban implementation resulted in a delay of early mortality that would have otherwise occurred in the absence of the smoking ban. When exposure to SHS was decreased, the likelihood of a mortality event being triggered in at-risk persons was immediately decreased. However, to achieve additional long-term gradual trends in mortality reductions, smoking prevalence and cigarette consumption would also need to be reduced. Since neither the prevalence of active smoking nor the number of cigarettes smoked per day in Ireland has decreased, it is feasible to deduce that existing social norms surrounding smoking behaviour have also not appreciably changed.

Furthermore, certain subgroups of the population, such as persons of low SES, may need additional help with smoking cessation since they are more likely to be addicted to nicotine. When compared to most other EU countries, Ireland currently designates much less funding for smoking cessation programs (IHF, 2013). As has been observed even in a middle-income country such as Uruguay, supplementary tobacco control policies such as full bans on tobacco sponsorship, free diagnosis and treatment for tobacco dependence at the primary health provider level, and graphic pictorial warnings on cigarette packaging can result in considerable decreases in tobacco use when implemented synergistically with a workplace smoking ban (Abascal et al., 2012). Ireland has recently adopted regulations for including graphic warnings on all tobacco packaging, wherein all products must be fully compliant by February 1, 2014 (ASH, 2013). Extended tobacco control legislation such as this, along with other aforementioned policies, is needed in Ireland to achieve decreases in active smoking and further reductions in exposure to passive smoking that may impact longer-term mortality reductions.

The third thesis study, an empirical analysis of Irish mortality data from 2000-2010, matched to area-level census data from 2002 and 2006 with linear interpolation for the remaining years, demonstrated that immediate post-ban mortality reductions in IHD, stroke, and COPD were either concentrated in the most deprived tertiles or equitably distributed across SES tertiles. Thus, the national Irish smoking ban was associated with reductions in existing area-level inequalities in mortality between the least and most deprived groups.

Although previous social research has indicated that different SES indicators are not always comparable measures of health inequalities (Davey Smith et al., 1998a; Geyer et al., 2006; Geyer & Peter, 2000; Macintyre et al., 2003), no other smoking ban research studies have explored the use of discrete SES indicators in examining post-ban effects. This study utilised four structural SES indicators: education, occupation, foreign nationality, and family composition, as well as three material SES indicators: unemployment, housing tenure, and car access, in discrete analyses. Indeed, the selection of SES indicators influenced the estimation of post-ban effects, with structural SES indicators yielding larger reductions than material SES indicators in discrete analyses.

Two previous smoking ban research studies have assessed SES differentials in post-ban mortality in an adult population (Cesaroni et al., 2008; Mackay et al., 2013), but only one of these studies necessitated the development of a census-based composite SES index (Cesaroni et al., 2008) as the other study employed an existing national index of multiple deprivation (Mackay et al., 2013). Although the study methodology in Cesaroni et al. (2008) indicated that a factor analysis was conducted to generate a composite index from variables representing five SES indicators of education, occupation, home ownership, family composition, and nationality, specific information was not provided on the variables included or whether PCA or common factor analysis was employed. In this thesis study, PCA was the preferred method because the extracted factors are actual, rather than hypothetical, combinations of the individual variables, explaining all of the variance in the correlation matrix (Kline, 1994). Nevertheless, in practice, when the correlation matrix is large, any differences between the two methods are trivial (Kline, 1994).

Composite analyses yielded more attenuated effects than discrete analyses; therefore, it is difficult to provide a single estimate of post-ban effects for each area-level SES tertile. However, when considered across all SES indicators, cause-specific mortality benefits were stronger in the most deprived. Both discrete and composite analyses were useful in the estimation of post-ban effects. While discrete analyses can elucidate information on individual census variables and provide additional knowledge regarding the applicability of the variable as an SES indicator, PCA accounts for the variance of the individual variables and provides a comparison measure to distinguish the best composite index for capturing SES differentials in post-ban effects.

Limitations and Strengths

For the review, the primary limitation was that access to EMBASE was not available. As EMBASE is arguably the most extensive and comprehensive biomedical database to date, every attempt was made to gain access. Examples included contacting the subject-specific librarian at Brunel University, searching for availability through the institutions of Irish collaborators (Dublin Institute of Technology and the TobaccoFree Research Institute), visiting institutions through the SCONUL scheme (King's College London and the University of Dundee, Scotland), and becoming a member of the National Library of Scotland in Edinburgh. Remote access to EMBASE was not available through the British Library as searches could only be conducted from within a science reading room. This was not feasible as multiple searches needed to be conducted as the project developed. Despite all this, article reference lists were continually monitored for any previously unidentified studies. Furthermore, when the recent meta-analysis of cardiovascular and respiratory morbidity and mortality was published, reporting the use of EMBASE for study identification (Tan & Glantz, 2012), there were only two additionally published articles (Sargent et al., 2012; Villalbi et al., 2011) that had not already been included in the thesis review project. Neither of the two studies had assessed post-ban effect differences by SES. Nonetheless, the studies were incorporated into the narrative synthesis, confirming that all relevant studies were identified.

The strengths of the review included its uniqueness in assessing smoking ban research studies of respiratory outcomes, which had not yet been done at the time the thesis research began, and in assessing effects by SES, which has to date only been done in this thesis and is of immense public health importance. The use of narrative synthesis allowed for the identification of areas of research that have not yet been addressed in relation to smoking ban policies and allowed for explication of the context of the studies rather than focusing only on the numerical range of effect estimates. The review methods were clearly defined, providing both transparency and reproducibility.

For the second thesis study, an empirical analysis, the major limitations were data-related. First, it would have been ideal to include a longer post-ban period than 3.75 years for the Chapter 3 mortality analyses; however, due to the general lag of a few years between actual deaths and the recording and release of data from the Irish Death Registry for research use, additional data were not available at the time analyses were conducted. Nevertheless, the inclusion of mortality data from three additional years (2008-2010) in the Chapter 4 mortality analyses confirmed that post-ban effects were indeed immediate. Second, as with any secondary data source, misclassification bias in the diagnostic coding of mortality events could not be ruled out. However, sensitivity analyses were conducted to determine if ICD coding changes influenced results or if demonstrable systematic coding bias was present. No evidence of such bias was detected. Third, mortality records do not provide information on smoking status. Because post-ban smoking prevalence did not appreciably change, it is likely that mortality rates in smokers also remained largely unchanged. Therefore, post-ban effects in non-smokers may have been underestimated. Although the estimated percentage of post-ban reductions due to active smoking was approximated, information on smoking status would have provided more precise estimates. Additionally, mortality records do not provide information on recent or historical SHS exposure. Such data would have allowed for differentiating between mortality trends in exposed and unexposed persons, potentially providing additional confirmatory evidence that post-ban mortality reductions were due to decreases in passive smoking.

Due to insufficient data, it was also not possible to adjust for the potential confounders of temperature and air pollution. However, seasonal adjustments were made in all regression models, partially accounting for time-varying weather-related confounders. A previous smoking ban research study also demonstrated that post-ban reduction estimates adjusted for apparent temperature and particulate air pollution were similar to crude estimates (Cesaroni et al., 2008).

The strengths of this study included the extensive post-ban assessment period of 3.75 years, which was the longest follow-up period of a national smoking ban at the time of study publication. The study was also distinctive in its examination of multiple causes of death, whereas most other research studies, particularly at the national level, focused on a single outcome. Additional study strengths included the corroboration of previous evidence of post-ban mortality reductions due to cardiovascular causes, further strengthening the available evidence for policymakers. Even more importantly, the study was novel in that it was the first to demonstrate post-ban mortality reductions due cerebrovascular and respiratory causes. The use of time-series analysis, accounting for underlying trends and additional confounding factors, provided strong evidence of post-ban mortality reductions, thereby minimising the accusations that tobacco industry supporters could make against the study methodology.

As with the second thesis study, the primary limitations for the third thesis study were also data-related. Accurate, individual-level SES information was not available in the routine Irish mortality data. Although the data included a variable representing occupational class, information was missing for 83% of records from 2000-2010; additionally, discourse with academic collaborators from Ireland indicated that even for the 17% remaining records for which occupational class had been coded, data were likely to be inaccurate. Therefore, SES was designated based upon local authorities, the smallest area-level classification to which mortality data could be assigned. Previous studies have highlighted that both individual and area-level indicators are important in the epidemiologic assessment of health inequalities; however, the context of the research question should be considered when deciding which level of SES indicator to employ for analyses (Diez-Roux, 2001; Krieger et al., 2003; Macintyre & Ellaway, 2000; Marmot, 2000). Indeed, administratively-defined areas are the most relevant geographic classification for analysing policy effects (Diez-Roux, 2001), allowing area characteristics to provide the context of conditions influential to individual health risks (Lynch & Kaplan, 2000). Hence, in this case, for the assessment of a smoking ban policy, which is a population-wide intervention, area-level indicators were appropriate.

Previous smoking ban research studies in England (Millett et al., 2013), Scotland (Mackay et al., 2010a), and New Zealand (Barnett et al., 2009) employed existing indices of multiple deprivation for analyses of post-ban differentials in health effects. However, the Republic of Ireland did not have a standardised index of multiple deprivation. Consultants for Pobal, a non-profit organisation, have now developed a deprivation index based upon 2006 and 2011 census data from the Republic of Ireland (Pobal, 2012), as an update to a previous index derived from 2001 Northern Ireland census data and 2006 Republic of Ireland census data (Haase et al., 2012), but neither of these indices were applicable for this thesis study as they did not consider indicators for occupation, foreign nationality, family composition, or car access; additionally, these indices did not include appropriate census data required to cover the 2000-2010 study period for mortality analyses in the Republic of Ireland. Due to these limitations, it was necessary to develop a Republic of Ireland census-based composite SES index, accounting for the study period and including important SES indicators, as identified in prior research.

However, for further validation of the effects detected in this study, deprivation index scores developed from the Irish census waves of 2002 and 2006, as previously published by social and economic consultants in 2008, were tested as sensitivity SES measures in this study. The deprivation scores were obtained from a historical document that is no longer available in the public domain, and were comprised of differing SES indicators than the ones employed in this study (Haase & Pratschke, 2008). Nevertheless, these sensitivity analyses confirmed that post-ban effects were either stronger in the more deprived groups or similar across tertiles, indicating that reductions in mortality inequalities occurred following smoking ban implementation in Ireland.

Although the Irish census was conducted in 2002 and 2006, the next census was not conducted until 2011. As such, information was not available to provide another data point in linear regression analyses of SES indicators spanning the 2000-2010 study period. Also, due to changes in the data collection forms, information was not always directly comparable between the 2002 and 2006 census waves. Thus, the combination of census response categories into groupings for analyses was restrictive in order to prevent capturing a response category that may have been artificially inflated due to changes in the way the census question was presented. Such was the case with the ‘all others gainfully occupied and unknown’ occupational response category. However, to minimise misclassification when combining response categories into groups, Spearman correlation tests were conducted to verify appropriate boundaries.

While income has been shown to be useful as an independent measure of SES (Geyer et al., 2006; Geyer & Peter, 2000), the Ireland census does not provide income information. The CSO produces a report on income in Ireland from other administrative data sources, but information was only available by region and by certain counties. For instance, Dublin was considered as a single county, with no distinction between Dublin City and Dún Laoghaire-Rathdown, whereas in the census and mortality data, a clear and important division was made since other SES indicators showed that these areas were generally at opposing ends of the SES spectrum. Since income data were not available for all local authority areas, material deprivation was represented by housing tenure and motor vehicle access as recommended in previous social research (Davey Smith & Egger, 1992; Davies et al., 1997; Macintyre et al., 1998).

Strengths of this study included the further validation of immediate post-ban effects as identified in the second thesis study, which persisted through a post-ban study period extended by three years. Moreover, this was the first study to include such an extensive post-ban study period of 6.75 years. This study was unique in examining the influence of discrete SES indicators on post-ban effect differences in a national population and in providing evidence of SES effect differences in COPD mortality, which has not been reported in any previous studies. Additionally, this study provided evidence of SES differences in post-ban IHD and stroke effects, which to date have rarely been assessed. The Republic of Ireland-specific composite SES index generated through PCA was based upon the most relevant census data for the study period, and composite analyses provided corroborative evidence to discrete SES results. Perhaps most importantly, the methods were clearly delineated, providing transparency and a clear rationale for each decision made in the methodological process.

Implications for Public Health Research, Policy, and Practice

The review and narrative synthesis highlighted the chronological development of epidemiological methods utilised in smoking ban research, from before-and-after comparison studies to interrupted time-series regression analyses. It is particularly important in public health research to employ methods accounting for long-term secular trends, to be transparent in justifying the methodological rationale, to consider potential confounding factors, to discuss contextual factors that could influence the association between a smoking ban policy and health outcome, and to declare funding bodies and potential conflicts of interest. Whenever new smoking ban research is published, it is immediately entered as evidence in the debate between tobacco industry supporters and health protection agencies. Therefore, it is crucial that public health researchers remain vigilant in transparency, thereby preventing by all means possible the undermining of research findings by individuals and industries that continually fight against health-protective policies that result in decreased tobacco use.

Though there is currently sufficient evidence of cardiovascular benefits following the implementation of smoking ban policies, there is a need for more research on post-ban cerebrovascular and respiratory effects, particularly in relation to mortality, which has hitherto not been explored. Of crucial importance is the need for public health research of smoking ban impacts on health inequalities. A human rights approach to public health should become the standard, not only giving precedence to improving overall health, but also considering the impacts on health inequalities (Marmot et al., 2012). Therefore, more evidence is needed to determine whether smoking ban policies result in any unintended consequences, such as worsening existing inequalities, or whether they are effective measures for decreasing inequalities. This type of policy evaluation should be an integral part of public health research. If unintended consequences are detected, targeted interventions can then be designed to aid subgroups of the population who may be adversely affected. The two empirical analyses in this thesis helped to address the evidence gap identified in the review by examining post-ban stroke and COPD mortality effects and subsequently assessing for SES differentials in the observed immediate effects. These studies demonstrated that the national Irish smoking ban was indeed an effective measure for reducing mortality and for narrowing the gap of mortality inequalities between the least and most deprived in Ireland.

For public health policymakers, the three studies of this thesis have highlighted the benefits of implementing strong, comprehensive smoking ban policies. Although the tobacco industry promotes accommodation strategies to policymakers, which allow both smoking and non-smoking sections in workplaces and hospitality venues, it has been proven that partial bans do not fully protect health, and in fact could worsen smoking-related inequalities in health. These accommodation strategies, then, are simply mechanisms for challenging the implementation of comprehensive smoking bans, and when successful, serve to destabilise the public health aim of protecting population health. Policymakers can rely on the strong public health research evidence base available in support of the health benefits of comprehensive, smoking ban policies covering workplaces and hospitality venues.

For public health practitioners involved in the pre-implementation phase of a smoking ban policy there are many facets to consider, such as being responsive to the media, preparing for issues relating to smoking ban compliance, and seeking provision of smoking cessation aids for persons aiming to quit. Specific recommendations for practitioners in cities or countries not currently covered but preparing to implement a smoking ban policy are to work closely with the communication division of the department of health to prepare clearly understandable messages regarding when, where, and why the smoking ban policy is being implemented. Prior to implementation, it is also important to ensure adequate resources for acquiring and training environmental health officers who will not only conduct inspections, but also help educate venue owners of appropriate compliance and to provide support by making them aware of their protection under the law when confronting potential violators of the legislation. Launching a smoking cessation campaign with the provision of cessation aids either preceding or coinciding with the implementation of the smoking ban policy may also aid in producing synergistic, long-term positive health outcomes that can result in de-normalising tobacco use. Concurrently, this demonstration of sensitivity and understanding towards the struggles of smokers who are attempting to quit represents to the public that the primary purpose of tobacco control policies is to protect health, not to marginalise smokers or to infringe on their personal rights as is often implicated by the tobacco industry. These measures should be followed up by policy evaluation in the post-implementation phase, reporting findings to the media, as warranted, to remind the public of the beneficial effects of the legislation and to provide encouragement for continuing with compliance.

CHAPTER 6: Conclusion

Tobacco smoking including secondhand smoke is the leading risk factor for death and disability-adjusted life years in North America and Western Europe and the second leading risk factor globally (Lim et al., 2012). Much of this immense disease burden is preventable, as decreases in smoking-related morbidity and mortality have been observed following the implementation of comprehensive smoking ban policies. Even minimal decreases in exposure can result in large public health benefits. This thesis research has therefore contributed new evidence of paramount public health importance.

The review and narrative synthesis of 37 primary epidemiological research studies was successful in identifying strong evidence of post-smoking ban reductions in cardiovascular morbidity and mortality and indicative evidence of post-ban reductions in respiratory morbidity. However, no evidence was available regarding post-ban effects in respiratory mortality. Most importantly, the review underscored the critical need for research on smoking ban impacts on health inequalities as only three studies had previously undertaken this research and with inconsistent findings. The chronological assessment of studies highlighted the development of epidemiological methods over time and aided in identifying the most applicable approach for conducting research on the health effects of smoking ban policies, including potential confounding factors that should be considered. The examination of the few studies assessing SES differentials in post-ban effects provided methodological guidance for how this may be effectively explored in future research. The narrative synthesis aided in identifying overarching themes and groupings of studies, identifying and emphasising areas in which the health effects of smoking ban policies and impacts on inequalities are yet unknown. Specifically, more research is needed in low and middle-income countries where the tobacco industry is now focusing marketing efforts.

The epidemiologic analysis of all-cause and cause-specific Irish mortality data from 2000-2007 examined post-ban effects over the longest follow-up period ever documented in an assessment of a national smoking ban policy. The interrupted time-series Poisson regression analysis accounted for underlying trends and allowed for the exploration of both immediate and long-term post-ban effects, while adjusting for seasonality, influenza epidemics, and smoking prevalence. This study demonstrated that the national, Irish comprehensive workplace smoking ban policy resulted in large, immediate mortality reductions in IHD, stroke, and COPD. The observed post-ban decreases in IHD served to confirm previous findings from epidemiological studies in other countries. However, the post-ban decreases in stroke and COPD were novel, never having been documented in published research. These post-ban reductions were predominantly the result of immediate reductions in exposure to SHS, as smoking prevalence did not appreciably change. The lack of long-term gradual trend effects supports the findings of a recent meta-analysis which determined that post-ban risk differences did not change with a longer follow-up period (Tan & Glantz, 2012). In the case of the Republic of Ireland, this may indicate that additional tobacco control measures are needed to aid in reducing active smoking, which would act to supplement the immediate decreases in population SHS exposure that occurred after smoking ban implementation.

The epidemiologic analysis of cause-specific Irish mortality data from 2000-2010, matched to appropriate census data to approximate area-level SES, addressed a major evidence gap as identified in the review and narrative synthesis by exploring smoking ban policy impacts on health inequalities. This study provided novel findings of SES differentials in post-ban mortality effects by discrete indicators of SES, capturing both structural and material aspects of living and working conditions in the Republic of Ireland. A composite SES index was generated through PCA, allowing the joint analysis of all discrete SES indicators, and accounting for the overall variance of each of the individual indicators. The trend of post-ban reductions in IHD was not always clear, with the largest decreases sometimes shifting between the most deprived and intermediate tertiles when examined across various SES indicators; however, post-ban stroke reductions exhibited a clearer trend, with statistically equitable mortality benefits detected across SES tertiles. For COPD, post-ban reductions were observed solely in the most deprived tertile.

These overall findings indicated that the national Irish smoking ban reduced inequalities in smoking-related mortality. Due to the higher rates of smoking-related mortality in the most deprived group, even equitable reductions across SES tertiles resulted in decreases in inequalities.

These three thesis studies have provided confirmatory and novel evidence of the large, public health impacts of smoking ban policies, employing a human rights approach to research by considering effects on overall population health as well as impacts on inequalities. This evidence encourages a broader implementation of smoking ban policies around the world as a simple and straightforward measure for reducing the global burden of disease.

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APPENDIX 1: Brunel University Ethics Approval Letter

Brunel
UNIVERSITY
WEST LONDON

University Research Ethics Committee

31 August 2011

Letter of Approval

Proposer: Sericea Smith
Institute for the Environment

Title: **Examining the mortality effects of the National Irish smoking ban**

Dear Mrs. Smith,

The University Research Ethics Committee has considered the document recently submitted by you in response to the Committee's earlier review of the above application.

The Chair, acting under delegated authority, is satisfied that the document accords with the decision of the Committee and has agreed that there is no objection on ethical grounds to the proposed study.

Any changes to the protocol contained in your application, and any unforseen ethical issues which arise during the project, must be notified to the Committee.

Kind regards,

D. Anderson-Ford

David Anderson-Ford
Chair, Research Ethics Committee
Brunel University

APPENDIX 2: Authored *PLoS One* Publication

OPEN ACCESS Freely available online

PLOS | ONE

Reductions in Cardiovascular, Cerebrovascular, and Respiratory Mortality following the National Irish Smoking Ban: Interrupted Time-Series Analysis

Sericea Stallings-Smith[1]*, Ariana Zeka[1]*, Pat Goodman[2,3], Zubair Kabir[4], Luke Clancy[3]

1 Institute for the Environment, Brunel University, London, United Kingdom, **2** Environmental Health Sciences Institute, Dublin Institute of Technology, Dublin, Ireland, **3** TobaccoFree Research Institute Ireland, Dublin, Ireland, **4** Department of Epidemiology and Public Health, University College Cork, Cork, Ireland

Abstract

Background: Previous studies have shown decreases in cardiovascular mortality following the implementation of comprehensive smoking bans. It is not known whether cerebrovascular or respiratory mortality decreases post-ban. On March 29, 2004, the Republic of Ireland became the first country in the world to implement a national workplace smoking ban. The aim of this study was to assess the effect of this policy on all-cause and cause-specific, non-trauma mortality.

Methods: A time-series epidemiologic assessment was conducted, utilizing Poisson regression to examine weekly age and gender-standardized rates for 215,878 non-trauma deaths in the Irish population, ages ≥35 years. The study period was from January 1, 2000, to December 31, 2007, with a post-ban follow-up of 3.75 years. All models were adjusted for time trend, season, influenza, and smoking prevalence.

Results: Following ban implementation, an immediate 13% decrease in all-cause mortality (RR: 0.87; 95% CI: 0.76–0.99), a 26% reduction in ischemic heart disease (IHD) (RR: 0.74; 95% CI: 0.63–0.88), a 32% reduction in stroke (RR: 0.68; 95% CI: 0.54–0.85), and a 38% reduction in chronic obstructive pulmonary disease (COPD) (RR: 0.62; 95% CI: 0.46–0.83) mortality was observed. Post-ban reductions in IHD, stroke, and COPD mortalities were seen in ages ≥65 years, but not in ages 35–64 years. COPD mortality reductions were found only in females (RR: 0.47; 95% CI: 0.32–0.70). Post-ban annual trend reductions were not detected for any smoking-related causes of death. Unadjusted estimates indicate that 3,726 (95% CI: 2,305–4,629) smoking-related deaths were likely prevented post-ban. Mortality decreases were primarily due to reductions in passive smoking.

Conclusions: The national Irish smoking ban was associated with immediate reductions in early mortality. Importantly, post-ban risk differences did not change with a longer follow-up period. This study corroborates previous evidence for cardiovascular causes, and is the first to demonstrate reductions in cerebrovascular and respiratory causes.

Citation: Stallings-Smith S, Zeka A, Goodman P, Kabir Z, Clancy L (2013) Reductions in Cardiovascular, Cerebrovascular, and Respiratory Mortality following the National Irish Smoking Ban: Interrupted Time-Series Analysis. PLoS ONE 8(4): e62063. doi:10.1371/journal.pone.0062063

Editor: Lamberto Manzoli, University of Chieti, Italy

Received December 22, 2012; **Accepted** March 17, 2013; **Published** April 24, 2013

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Funding: These authors have no support or funding to report.

Competing Interests: The authors have declared that no competing interests exist.

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Introduction

Exposure to secondhand smoke increases the risk of morbidity and premature mortality due to cardiovascular [1], cerebrovascular [2], and respiratory [1] causes. On March 29, 2004, the Republic of Ireland became the first country in the world to implement a national workplace smoking ban. The legislation was comprehensive, banning smoking in workplaces including restaurants, bars, and pubs.

Following the implementation of the Irish national smoking ban, studies conducted in pubs and bars demonstrated reductions in particulate concentrations [3], reductions in worker-reported exposure to secondhand smoke [4,5], and related improvements in worker pulmonary function [3] and self-reported respiratory symptoms [5]. More recent Irish studies have shown post-ban reductions in hospital admissions due to acute coronary syndromes [6,7] and acute pulmonary disease [7]. Epidemiological studies of the effects of comprehensive smoking bans in other countries have demonstrated reductions in mortality due to cardiovascular causes [8–11] and hospital admissions due to cardiovascular [11–20], cerebrovascular [12,20], and respiratory causes [12,20,21]. Most of the studies analyzed a post-ban follow-up period of 2.5 years or less [8–20], with only one study analyzing a post-ban time period of 3.5 years [21]. None of the studies analyzed post-ban mortality effects in cerebrovascular or respiratory causes. The aim of this study was to assess the effect of the national smoking ban on all-cause and cause-specific, non-trauma mortality in the Republic of Ireland for the years 2000–2007.

Methods

Data for the Republic of Ireland

National mortality data from January 1, 2000, to December 31, 2007, were obtained from the Central Statistics Office (CSO)

Ireland. From 2000–2006, mortality data were coded according to the *International Classification of Diseases, 9th Revision* (ICD-9); ICD-10 codes were implemented in 2007. Primary causes of death selected for analyses included all-cause, non-trauma mortality (ICD-9 codes 001-799/ICD-10 codes A00-R99), smoking-related mortality including all cardiovascular diseases (390-429/I01-I52), ischemic heart disease (IHD) (410-414, 429.2/I20-I25), acute myocardial infarction (AMI) (410/I21), stroke (430-438/I60-I69), all respiratory diseases (460-519/J0-J99), and chronic obstructive pulmonary disease (COPD) (490–492, 494–496/J40–J44, J47). Non-smoking related mortality (001–389, 440–459, 520–799/A00–H95, I26–I52, K00–R99) was included as a control.

Age and gender-specific population estimates for the census years 2002 and 2006 were obtained from the CSO Ireland [22].

Statistical Analyses

Poisson regression with interrupted time-series analysis was used to calculate weekly mortality rates. The average of age and gender-specific population figures for census years 2002 and 2006 was included as an offset in the models. Time was defined as a continuous variable from week 1 of 2000 to week 51 of 2007 and was included in the model to capture long-term trends in mortality rates over time. Week 0 of 2000 and week 52 of 2007 were excluded from analyses as some days fell in other calendar years.

An indicator variable was used to define the smoking ban, with a value of zero given to the weeks before ban implementation and a value of one given to the week of ban implementation (beginning March 28, 2004) and all following weeks. An interaction term between the smoking ban and time was defined to estimate the monotonic change in the post-ban period. The analysis was restricted to mortality events in age groups ≥35 years to reflect the population at risk for smoking-related mortality.

Significant Durbin-Watson statistics indicated negative first-order autocorrelation for the mortality data. To account for this, terms specifying a first-order autoregressive structure were applied to all models.

In 2007, the change in coding scheme from ICD-9 to ICD-10 resulted in a 43% decrease in pneumonia/influenza mortality compared to 2006. Since roughly 49% of all respiratory mortality was comprised of pneumonia/influenza over the 2000-2006 study period, the large decrease in 2007 affected data reliability for this category. Therefore, 2007 data were excluded from analyses of all respiratory mortality. No other causes of death were affected by the coding change.

To detect any differences between short-term and long-term post-ban mortality effects, an additional indicator variable was included in final models. Values of one were given for the week of ban implementation and the subsequent weeks up to one, three, six, or twelve months post-ban, with all other weeks denoted by a value of zero.

For further validation that the final models were detecting true ban effects, three additional models were refitted with false smoking ban implementation dates set at six months, one year, and two years pre-ban.

A peak in observed mortality was detected during the winter of 1999–2000; therefore, two additional models were tested to determine whether the full inclusion (beginning December 1999) or full exclusion (beginning April 2000) of the winter season influenced model results.

To determine the modifying effects of age and gender on the smoking ban-mortality association, analyses were stratified for ages 35–64 years, ages 65–84 years, and ages ≥85 years, males, and females. Due to the small number of events in each subcategory, it was not possible to stratify by age and gender simultaneously.

Potential Confounders

Adjustments were made for temporal changes in season [23,24], influenza activity [25], and national smoking prevalence. Season was designated based upon calendar weeks with winter defined as December-February, spring as March-May, summer as June-August, and autumn as September-November. Seasonal adjustment with annual and semi-annual sine and cosine terms yielded similar effects.

Weekly surveillance data for influenza-like illnesses (ILI) were available from the Irish Health Protection Surveillance Centre [26] for the influenza seasons (October-May) of 2000–2001 to 2007–2008. ILI activity for the influenza season of 1999–2000 was approximated using published data from the European Influenza Surveillance Scheme [25]. Periods of high ILI activity were defined as weeks when the reported rate of ILI was ≥60/100,000, roughly twice the background rate of ILIs for the Republic of Ireland.

Monthly smoking prevalence data from a nationally representative computer-assisted telephone survey of 1,000 persons per month, ages ≥15 years, were obtained from the Ireland Office of Tobacco Control (OTC) [27]. Data were available for the months of July 2002–December 2007. A linear regression fitted to OTC data was used to approximate smoking prevalence for 2000–2001. Annual averages were calculated to adjust for smoking prevalence in all models.

Presentation of Results

The Poisson model equation estimating weekly morality rates was expressed as follows:

$$Log(E(Y)) = \beta_0 + \beta_1 TimeW + \beta_2 BAN + \beta_3 (TimeW * BAN) + \beta_k (SP, I, Season) + e \tag{1}$$

where Y denotes the response (weekly mortality), β_0 is the model intercept, β_1 is the model coefficient for the weekly time trend variable, β_2 is the coefficient of the indicator variable for smoking ban policy implementation, β_3 is the coefficient of the interaction between the indicator variable for BAN and the weekly time trend, β_k denotes the effects for a set of covariates of interest (*smoking prevalence-SP, influenza-I, and Season*), and e is the model error term.

In the pre-ban period (Figure 1), *Ban* =0, and the model takes the form:

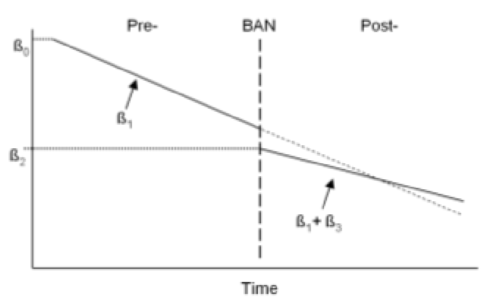

Figure 1. Interpretation of model results. The Y axis represents weekly mortality, the X axis represents Time, and the bold line represents the monotonic mortality change pre- and post-ban. The vertical interrupted line represents the time of the smoking ban policy implementation.
doi:10.1371/journal.pone.0062063.g001

$$Log(E(Y)) = \beta_0 + \beta_1 TimeW + \beta_k(SP,I,Season) + e \quad (2)$$

In the post-ban period, *Ban* = 1, thus the model takes the form:

$$Log(E(Y)) = (\beta_0 + \beta_2) + (\beta_1 + \beta_3)TimeW + \beta_k(SP,I,Season) + e \quad (3)$$

where β_2 is the change in the log rate ratio for the immediate effect of the smoking ban and $(\beta_1 + \beta_3)$ is the post-ban rate of change in mortality, with β_3 representing the change in slope after the ban. For results presentation, rate ratios (RR) were calculated for the immediate effect coefficients as$[\exp(\beta_2)]$, and weekly trend effect coefficients were converted to annual change with$[\exp(\beta_1 + \beta_3) * 52]$. The 95% confidence intervals (CI) for the annual trend effect accounted for the overall variance of the pre- and post-ban slopes with the formula $[\exp((\beta_1 + \beta_3) * 52 \pm 1.96 * (SQRT(Var(\sum \beta_{1,3})) * 52))]$, with $Var(\sum \beta_{1,3})$ determined as $[\sum Var(\beta_{1,3}) + \sum Cov(\beta_{1,3})]$, where $\sum Var(\beta_{1,3})$ is the sum of pre- and post-ban slope variance and $\sum Cov(\beta_{1,3})$ is the sum of the pre- and post-ban slope covariance [28,29].

All analyses were conducted using SAS version 9.2, and statistical modeling was carried out with the SAS GLIMMIX procedure, allowing adjustment for autocorrelation [30].

Number of Deaths Prevented

The predicted incremental number of deaths that would have occurred in the absence of a national smoking ban for each of the 3.75 post-ban years (April 2004–December 2007) were calculated as follows: Predicted deaths$_i$ = [Observed deaths$_j$ - (Observed deaths$_j$*Pre-ban annual change)], where *i* represents each post-ban year, and *j* denotes the number of annual deaths from the preceding year.

Active Smoking Attributable Risk

To determine the extent to which observed mortality reductions in the first post-ban year were attributable to decreases in active smoking, the appropriate relative risks for IHD, stroke, and COPD in active and former smokers were derived from the published literature [31–36] and applied to an attributable risk formula previously published by Barone-Adesi *et al* [31]. To support these analyses, crude and model-estimated changes in pre- and post-ban monthly smoking prevalence were calculated to determine whether ban implementation affected smoking prevalence in the population.

Results

During the study period, 215,878 non-trauma deaths occurred in the Irish population ages ≥35 years. The population at risk was 1.9 million, mean figures from the 2002 and 2006 censuses. Seasonal variations in mortality were detected, with the largest number of deaths occurring in autumn and winter. From 2000–2007, an overall decrease in mortality rates was observed for all smoking-related causes of death with decreases becoming more pronounced in the post-ban period (Figures 2 and S1). In contrast, non-smoking related mortality showed a sharp increase in 2006 which continued throughout the end of the study period.

From 2000–2007, five periods of increased ILI activity were identified, with the largest period of increase occurring for eight consecutive weeks in the latter part of the 2000–2001 influenza season.

Results of the Poisson regression analyses demonstrated that all-cause mortality rates decreased in the pre-ban period (RR: 0.98; 95% CI: 0.96–0.99). Similar pre-ban reductions were found for all cardiovascular causes, IHD, AMI, stroke, and COPD. No pre-ban mortality effects were seen in the all respiratory category or for non-smoking related mortality (data not shown).

Overall and gender-specific post-ban results of Poisson regression analyses are reported in Table 1. Following the implementation of the ban, an immediate 13% decrease in all-cause mortality was observed (RR: 0.87; 95% CI: 0.76–0.99). Likewise, an immediate 26% reduction in mortality was seen in IHD (RR: 0.74; 95% CI: 0.63–0.88), a 32% reduction in stroke (RR: 0.68; 95% CI: 0.54–0.85), and a 38% reduction in COPD (RR: 0.62; 95% CI: 0.46–0.83). IHD and stroke reductions were observed in both genders, but reductions in all respiratory mortality were seen only in females (RR: 0.64; 95% CI: 0.42–0.98) driven by reductions in COPD (RR: 0.47; 95% CI: 0.32–0.70).

In contrast, an immediate 15% decrease was observed for non-smoking related mortality (RR: 0.85; 95% CI: 0.75–0.97), followed by a 5% increase each post-ban year (RR: 1.05; 95% CI: 1.02–1.08). This resulted in a net post-ban increase of 4%. No annual trend effects in post-ban mortality were detected for any smoking-related causes of death.

Table 2 displays Poisson regression results stratified by age category. For ages 35–64 years, an immediate post-ban decrease in all-cause mortality was observed (RR: 0.79; 95% CI: 0.67–0.93), followed by annual trend increases in all-cause mortality (RR: 1.06; 95%: 1.02–1.10), resulting in a net post-ban increase of 2%. For ages 65–84 years, immediate decreases were seen in all-cause mortality (RR: 0.87; 95% CI: 0.75–0.99). Similar immediate decreases were observed in IHD, stroke, and COPD for ages 65–84 years and for ages ≥85 years.

The inclusion of additional post-ban indicator variables at one, three, six, and twelve months implied only short-term ban effects. The testing of false ban implementation dates showed that immediate mortality effects were either non-significant or smaller in magnitude compared to actual ban effects. Only AMI showed a larger effect with the false date of one year pre-ban which coincided with the announcement by the Irish Minister for Health that a ban was to come into force on March 29, 2004. Additional sensitivity analyses demonstrated that model results were largely unaffected by the 1999–2000 winter peak in mortality, with no differences in effects observed for any smoking-related causes of death.

In the absence of a national smoking ban, an estimated 3,726 (95% CI: 2,305–4,629) additional smoking-related deaths would have occurred. This crude estimate indicates that reductions occurred in respiratory (up to 2006, 1,896 deaths; 95% CI: 1,517–2,152), cardiovascular (1,508 deaths; 95% CI: 690–1,926), and stroke mortality (322; 95% CI: 98–552). No deaths were prevented in association with non-smoking related mortality.

The resulting mortality decreases following smoking ban implementation were primarily due to reductions in passive smoking. The attributable risk calculations for IHD, stroke, and COPD respectively demonstrated that <1% of smoking ban effects was due to decreases in active smoking. Additional analyses assessing the change in smoking prevalence in the Irish population as a result of ban implementation showed no observable effects.

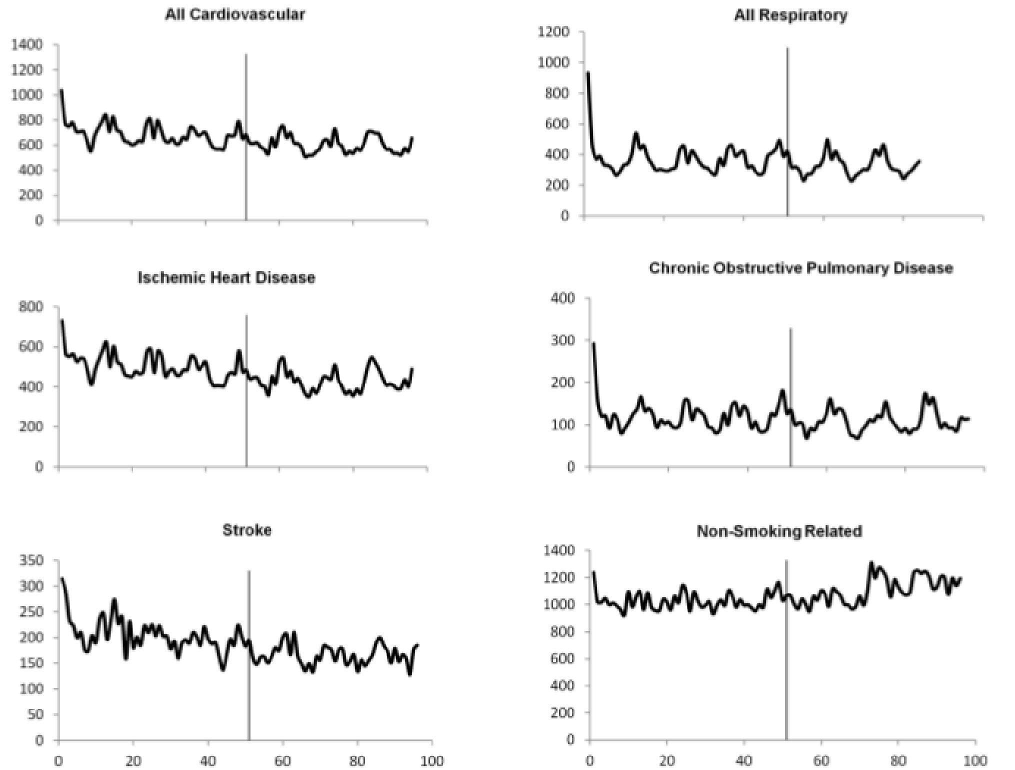

Figure 2. Observed Monthly Mortality in the Republic of Ireland, 2000–2007.* *All Respiratory excludes data from year 2007. The vertical line represents the month of smoking ban implementation. Monthly mortality is displayed rather than weekly for a clearer visual representation of trends.
doi:10.1371/journal.pone.0062063.g002

Table 1. Multivariate Analysis[†] of Overall and Gender-Specific Post-Ban Effects on Mortality Rates[‡], Ages ≥35 years, Republic of Ireland, 2000–2007.

	Overall		**Males**		**Females**	
Cause of Death	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**	**Immediate Effects**	**Gradual Effects per Annum**
	RR (95% CI)	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**	**RR (95% CI)**
All-Cause Mortality	0.87 (0.76–0.99)	1.01 (0.98–1.05)	0.87 (0.76–1.00)	1.01 (0.98–1.05)	0.86 (0.74–0.99)	1.01 (0.98–1.05)
All Cardiovascular	0.86 (0.74–1.00)	0.99 (0.95–1.03)	0.85 (0.72–1.02)	0.99 (0.95–1.03)	0.87 (0.72–1.04)	0.99 (0.95–1.04)
Ischemic Heart Disease	0.74 (0.63–0.88)	1.00 (0.96–1.04)	0.71 (0.58–0.86)	1.01 (0.96–1.05)	0.79 (0.64–0.97)	1.00 (0.95–1.05)
Acute Myocardial Infarction	0.89 (0.74–1.08)	0.97 (0.92–1.02)	0.87 (0.70–1.10)	0.97 (0.91–1.02)	0.92 (0.71–1.18)	0.97 (0.91–1.03)
Stroke	0.68 (0.54–0.85)	1.00 (0.95–1.05)	0.66 (0.49–0.89)	0.99 (0.92–1.06)	0.69 (0.53–0.91)	1.01 (0.94–1.07)
All Respiratory*	0.77 (0.54–1.10)	1.01 (0.92–1.10)	0.93 (0.63–1.38)	0.98 (0.89–1.07)	0.64 (0.42–0.98)	1.04 (0.94–1.14)
COPD	0.62 (0.46–0.83)	1.03 (0.96–1.11)	0.78 (0.55–1.12)	1.01 (0.92–1.09)	0.47 (0.32–0.70)	1.07 (0.97–1.16)
Non-Smoking Related Mortality	0.85 (0.75–0.97)	1.05 (1.02–1.08)	0.85 (0.73–1.00)	1.06 (1.02–1.09)	0.84 (0.71–0.99)	1.04 (1.00–1.08)

[†]Adjusted for time trend, season, influenza, and smoking prevalence.
[‡]Age and gender-standardized according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.
doi:10.1371/journal.pone.0062063.t001

Table 2. Multivariate Analysis† of Post-Ban Effects on Mortality Rates by Age Category‡, Republic of Ireland, 2000–2007.

Cause of Death	Ages 35–64 Years Immediate Effects RR (95% CI)	Ages 35–64 Years Gradual Effects per Annum RR (95% CI)	Ages 65–84 Years Immediate Effects RR (95% CI)	Ages 65–84 Years Gradual Effects per Annum RR (95% CI)	Ages ≥85 Years Immediate Effects RR (95% CI)	Ages ≥85 Years Gradual Effects per Annum RR (95% CI)
All-Cause Mortality	0.79 (0.67–0.93)	1.06 (1.02–1.10)	0.87 (0.75–0.99)	0.99 (0.96–1.03)	0.94 (0.80–1.10)	1.02 (0.98–1.06)
All Cardiovascular	0.91 (0.69–1.20)	0.98 (0.91–1.05)	0.86 (0.73–1.02)	0.97 (0.93–1.01)	0.86 (0.70–1.05)	1.03 (0.98–1.08)
Ischemic Heart Disease	0.74 (0.53–1.02)	1.01 (0.93–1.08)	0.74 (0.61–0.89)	0.98 (0.94–1.03)	0.78 (0.62–0.99)	1.04 (0.99–1.10)
Acute Myocardial Infarction	0.89 (0.58–1.36)	0.97 (0.86–1.07)	0.90 (0.71–1.13)	0.94 (0.89–1.00)	0.94 (0.71–1.26)	1.01 (0.94–1.09)
Stroke	0.66 (0.37–1.18)	1.00 (0.86–1.14)	0.75 (0.57–0.99)	0.96 (0.90–1.03)	0.61 (0.44–0.83)	1.05 (0.97–1.13)
All Respiratory*	1.59 (0.75–3.39)	0.93 (0.75–1.11)	0.71 (0.47–1.05)	1.01 (0.91–1.10)	0.75 (0.48–1.17)	1.03 (0.92–1.14)
COPD	0.74 (0.32–1.72)	1.04 (0.83–1.24)	0.68 (0.48–0.96)	1.01 (0.92–1.09)	0.49 (0.31–0.78)	1.09 (0.98–1.20)
Non-Smoking Related Mortality	0.72 (0.60–0.86)	1.10 (1.06–1.14)	0.86 (0.75–1.00)	1.03 (0.99–1.06)	1.03 (0.85–1.25)	1.05 (1.01–1.10)

†Adjusted for time trend, season, influenza, and smoking prevalence.
‡Age and gender-standardized according to average census population figures for 2002 and 2006.
*All Respiratory excludes data from year 2007.
doi:10.1371/journal.pone.0062063.t002

Discussion

The implementation of a national comprehensive smoking ban in the Republic of Ireland was associated with immediate mortality reductions in the population aged ≥35 years. After adjusting for time trend, seasonal variation, periods of high influenza activity, and national smoking prevalence, immediate post-ban reductions were observed in all-cause, IHD, stroke, and COPD mortality, indicating that the immediate removal of exposure to passive smoking was effective in preventing early mortality in the population most at risk.

No gradual post-ban trend effects were seen in any smoking-related causes of death. These findings are compatible with a similarly-designed analysis of the effects of the Scottish national smoking ban on pregnancy complications, which detected immediate step change reductions, but no gradual effects [37]. Importantly, the most recent meta-analysis of 45 smoking ban effect studies demonstrated that post-ban risk differences in cardiovascular deaths and hospital admissions for cardiovascular, cerebrovascular, and respiratory diseases did not change with a longer follow-up period [38]. This provides strong epidemiological evidence that smoking ban effects are seen immediately rather than gradually.

The decreases in IHD and stroke mortality were evident in both genders, while decreases in all respiratory and COPD mortality were noted for females. Stratification by age categories demonstrated cause-specific reductions for IHD, stroke, and COPD in ages ≥65 years. In contrast, for non-smoking related mortality both immediate post-ban reductions and gradual trend effects were detected, resulting in an overall post-ban increase.

The post-ban IHD reductions are consistent with the findings of two Irish studies, one of which demonstrated 12% reductions in hospital admissions due to acute coronary syndrome (ACS) in the first year following smoking ban implementation, with further reductions of 13% in the third post-ban year [6] and the other which showed an 18% decrease in ACS admissions for the oldest age groups (50–69 years) in the two post-ban years compared to the two pre-ban years [7]. Additional corroborative evidence from other countries includes decreases in out-of-hospital deaths due to acute coronary events for ages 35–64 years (15%) and ages 65–74 years (16%) one year following implementation of the Italian national smoking ban [10] and a 6% decrease in out-of-hospital ACS deaths in the 10 months following implementation of the Scottish national smoking ban [11].

This study has been the first to demonstrate post-ban reductions in stroke mortality. These findings are corroborated by prior studies reporting post-ban reductions in stroke hospital admissions. One study assessing the effects of a three-phase, province-wide smoking ban in Ontario, Canada, reported a 24% reduction in stroke hospital admissions following the second phase of the legislation, which expanded the existing partial workplace ban to include restaurants [20]. A study evaluating the effects of the Arizona statewide smoking ban demonstrated decreases in hospital admissions due to acute stroke (14%; $p = 0.001$) in the first post-ban year for counties that did not have prior local smoking legislation in place [12]. Although a study of the effects of the New York statewide smoking ban found no effects in stroke admissions in the first post-ban year, the authors suggested that previously enforced local smoking restrictions resulted in low secondhand smoke exposure among residents [18].

This has also been the first study to report smoking ban effects on respiratory mortality, with decreases in all respiratory mortality detected in females and decreases in COPD mortality detected overall, in females, and in persons aged ≥65 years. These findings are supported by a study that reported overall decreases in COPD hospital admissions following a province-wide smoking ban in Ontario, Canada [20]. Although a recent Irish study did not find post-ban decreases in COPD hospital admissions in the two post-ban years compared to the two pre-ban years, a 15% decrease in overall pulmonary admissions was detected in the same period [7].

The public health importance of the Irish national smoking ban is strongly demonstrated in estimates of the number of deaths prevented in the post-ban years. There were 3,726 fewer smoking-related deaths than would have been expected in the absence of a smoking ban. This number of prevented deaths is slightly attenuated when compared to the immediate percent reductions represented by the model, considering that model estimates account for gradual trends and other contributing factors.

The results of the attributable risk calculations for IHD mortality, which demonstrated that <1% of smoking ban effects was due to decreases in active smoking, are in concurrence with the findings of two studies that assessed the cardiovascular health effects of the national Italian smoking ban [10,31]. These studies showed that 0.7% of the estimated post-ban reductions in hospital admissions due to AMI [31] and <2% of the estimated post-ban reductions in hospital admissions and out-of-hospital deaths due to acute coronary events [10] were due to changes in active smoking in the first post-ban year.

Attributable risk calculations also showed that reductions in active smoking accounted for <1% of post-ban reductions in stroke and COPD mortality, but no corroborative studies are available to make comparisons as this is the first study to assess post-ban effects in these mortality outcomes. Nevertheless, these results were supported in that no observable change in smoking prevalence was seen in Ireland as a result of the ban. Together, these findings suggest that mortality benefits were the result of reductions in exposure to passive smoking.

Rapid physiological changes occur within minutes to hours of exposure to passive smoke, increasing risk of adverse cardiovascular and cardiopulmonary events [39,40] and resulting in effects in non-smokers that are 80% to 90% as large as those experienced by chronic, active smokers [41]. Exposure to even low levels of passive smoke decreases oxygen delivery to the heart as the carbon monoxide from cigarette smoke competes with oxygen for binding sites on red blood cells [42]. This impaired oxygen delivery to the heart particularly affects persons with existing cardiovascular disease, increasing arrhythmias and causing ischemia [42]. This and other related evidence has resulted in the recommendation that clinicians advise the families of patients with existing cardiovascular disease not to smoke while the patient is present [35,39]. The implementation of the national Irish smoking ban resulted in an immediate removal of exposure to passive smoke in workplaces and public places, therefore likely reducing population risk of experiencing the aforementioned triggers of an adverse cardiovascular or cardiopulmonary event, particularly for those with existing disease.

Information from the Survey of Lifestyle, Attitudes, and Nutrition (SLÁN), a national survey of the Irish population ages ≥18 years, was used to investigate trends in cardiovascular and respiratory risk factors over the study period. For the years 1998 and 2002, SLÁN data were collected through self-administered, postal questionnaires, but in 2007, data were collected through face-to-face interviews conducted in the homes of respondents. As such, 2007 figures may not be directly comparable to those of previous survey waves. However, obesity prevalence and levels of physical activity remained steady across the study period. The percentage of persons consuming over the recommended weekly alcohol limit decreased in the 2007 survey wave; however, this result should be interpreted with caution as persons may have been less likely to report high levels of alcohol consumption in face-to-face interviews [43].

Due to excise tax increases in Ireland, cigarettes prices increased by more than 10% in 2000, 2003, and 2007; however, the estimated effects on smokers aged ≥35 years were minimal [44]. In 2002, Ireland adopted non-graphic, non-pictorial, health warnings for cigarette packages, and extended the existing TV and print media advertising ban to include selected types of indirect advertising [44]. The advertising ban was further extended in 2004, but product placements and certain forms of sponsorship were still allowed [44]. Although these additional tobacco control interventions may have resulted in synergistic health improvements with the national smoking ban, their estimated effects were small and gradual and are thus insufficient to explain the large mortality reductions detected immediately following the implementation of the national smoking ban.

A few limitations of this study should be addressed. Direct adjustments for weather were not possible due to the small number of weekly mortality events remaining after stratification by age, gender, and region. Nonetheless, adjustment for seasonal variation in all models partially accounts for weather effects. Likewise, data limitations prevented assignment of air pollution measures to individual mortality events. However, following implementation of a series of coal bans across Ireland's major cities from 1990–2000, large declines in black smoke were noted [45], along with subsequent reductions in cardiovascular and respiratory mortality in Dublin [46]. These air quality improvements may partly explain the pre-ban mortality decreases detected in this study.

A key strength of this study was the use of time-series analysis, which accounts for secular trends by design and is therefore the strongest method for assessing the effects of a broad-based intervention such as a national policy change [47]. Additionally, this study was unique in that post-ban effects in multiple causes of death were examined, including deaths due to cerebrovascular and respiratory diseases which have not been reported in any prior studies, and the post-ban follow-up period was more extensive than any other previously reported.

Conclusion

The national smoking ban in the Republic of Ireland was associated with immediate reductions in early mortality, with specific benefits observed in cardiovascular, cerebrovascular, and respiratory causes. Importantly, post-ban risk differences did not change with a longer follow-up period. As a result of the ban, unadjusted estimates indicate that 3,726 smoking-related deaths were likely prevented. This study provides further evidence of the large public health impacts of smoking ban legislation.

Supporting Information

Figure S1 Weekly Age and Gender-Standardized Mortality Rates, Republic of Ireland, 2000-2007.* *All Respiratory excludes data from year 2007. The vertical line represents the week of smoking ban implementation.
(TIFF)

Acknowledgments

We thank Joel Schwartz, PhD, of the Harvard School of Public Health for his helpful comments on the paper.

Author Contributions

Conceived and designed the experiments: AZ PG LC SSS. Performed the experiments: SSS AZ. Analyzed the data: SSS AZ. Contributed reagents/materials/analysis tools: PG LC ZK. Wrote the paper: SSS AZ PG ZK LC.

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