Pollution and Mortality in the 19th Century*

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Abstract

The industrial cities of 19th century England were incredibly unhealthy places to live. This study highlights the important role played by industrial pollution in increasing mortality during this period using data covering over 500 districts in England from 1851-1900. To overcome the lack of direct pollution measures, I combine new data on the industrial composition of districts with measures of the pollution intensity of industries in order to infer local pollution levels. In order to obtain causal estimates, I offer several identifications strategies for overcoming selection effects and omitted variables. I find that a one standard deviation increase in industrial pollution raised district mortality by between 2.8 and 6.6 percent of overall mortality in 1851-1860. Moreover, industrial pollution explains roughly 20 percent of the urban mortality penalty in this period. These effects were concentrated in cause-of-death categories commonly associated with air pollution, particularly respiratory diseases. From 1851-1900, increasing pollution related to industrial coal use raised mortality by 0.65-1.57 per thousand, offsetting 13-26% of the mortality gains over this period. Finally, I show that pollution spillovers affected mortality in districts downwind of the main industrial centers. These results provide the first rigorous and broad-based evidence on the effect of pollution on mortality in the 19th century.

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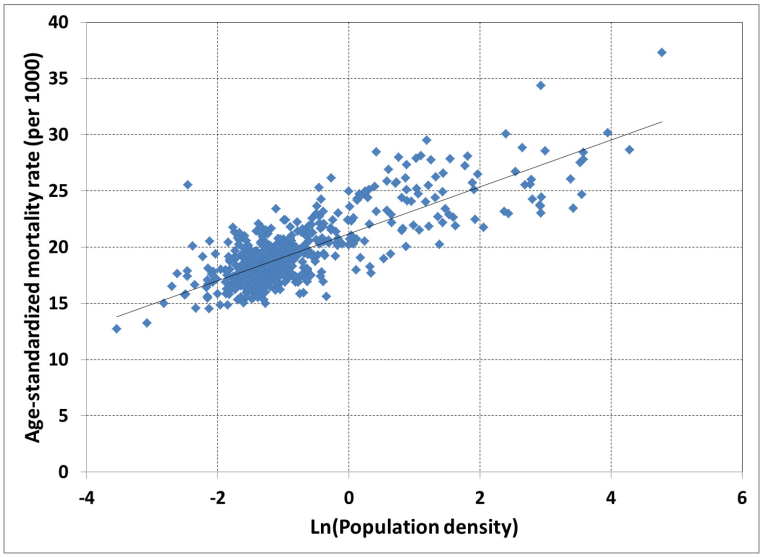
1 Introduction

In the 19th century, urban areas were incredibly unhealthy places to live. For example, Figure 1 describes the relationship between age-standardized mortality and district population density for 527 districts in England in 1851. Similar patterns have been shown for the United States (Cain & Hong (2009)) and France (Kesztenbaum & Rosenthal (2011)).

Figure 1: The Urban Mortality Penalty in England in 1851-1860



Mortality data for 527 English districts averaged over 1851-1860 from the Registrar General's reports.

What caused the urban mortality penalty in the 19th century? One leading answer to this question is based on the disease environment. With a large population crowded closely together, the theory goes, infectious disease transmission increased. Particular emphasis has been placed on transmission through unsanitary water (Troesken (2002), Cutler & Miller (2005), Ferrie & Troesken (2008), Kesztenbaum & Rosenthal (2012), Alsan & Goldin (2014)). A recent review suggests that the impact of the urban disease environment was so significant that, "The preponderance of the evidence suggests that the lack of improvement in mortality between 1820 and 1870 is due in large part to the greater spread of disease in newly enlarged cities" (Cutler *et al.* (2006)). A second potential cause may be poor nutrition, a channel emphasized by McKeown (1976), Fogel (2004), and Fogel & Costa (1997). If residents of larger cities were also poorer, or had less access to quality food, then poor nutrition may explain part of the urban mortality penalty.[1]

This paper highlights a third important determinant of mortality in the 19th century: industrial pollution. Pollution, particularly air pollution from coal burning in factories and homes, was a characteristic feature of English cities in the 19th century. News reports complained that, "There was nothing more irritating than the unburnt carbon floating in the air; it fell on the air tubes of the human system, and formed a dark expectoration which was so injurious to the constitution; it gathered on the lungs and there accumulated."[2] Contemporary reports and the work of historians suggest that air pollution levels were extremely high in British cities during this period.[3] At the same time, a large modern literature has highlighted the effect of pollution on mortality, primarily using data from the U.S. and Europe, where pollution levels are much lower than in the historical setting I consider.[4] Despite this evidence, pollution is often overlooked as an important determinant of mortality during the 19th century because we lack direct measurements of the magnitude of the impact of pollution during this period. This is largely because, outside of a few special cases, no direct pollution measures are available.

The goal of this paper is to provide the first broad-based and well identified estimates of the impact of pollution on mortality during the 19th century. Specifically, I focus on the impact of industrial pollution in England from 1851-1900, using data from 527 districts spanning nearly the entire country outside of London.[5]

One major challenge in studying pollution during this period is the lack of direct pollution measures. To overcome this, I propose an approach in which the industrial composition of the district is used as a proxy for the level of pollution. Detailed

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[1] This nutritional deficiency may have been further exacerbated by the extra calories needed to fight infectious disease.

[2] *Times*, Feb. 7, 1882 p. 10, quoted from Troesken & Clay (2011).

[3] Brimblecombe (1987) estimates that air pollution levels in London reached over 600 micrograms per cubic meter. For comparison, modern readings from Delhi, India are generally under 400 micrograms per cubic meter (Fouquet (2011)). Additional qualitative evidence comes from Mosley (2001), Thorsheim (2006) and others.

[4] This literature is far too large to review here. Graff Zivin & Neidell (2013) provides a recent review of some of the literature in this area.

[5] London is excluded because its size makes it a substantial outlier. In addition, a small number of districts are excluded because changes to the district boundaries make it impossible to generate consistent series.

data on the industrial composition of employment in each district were gathered from the Census of Population of 1851 and used to construct two measures of the level of industrial pollution in a district. The first measure uses information on the amount of coal used per worker in each industry, together with district employment, to construct an estimate of district coal use intensity. The second measure is based on employment in a set of industries that are known to be polluting. This approach provides district-level industrial pollution estimates which can be compared to the detailed mortality data available from the Registrar General's reports for this period.

To generate causal evidence this paper must confront issues related to the selection of less healthy populations into more polluted areas and omitted variables that may be correlated with both local industrial composition and local mortality. Several strategies are offered for dealing with these concerns.

One approach that can help with both selection and omitted variables issues is to exploit cause-of-death data. The idea behind this approach is that if the relationship between pollution and mortality is driven by selection of less healthy populations into more polluted areas, then this effect should appear across many cause-of-death categories. In contrast, if this relationship is driven by the direct effects of pollution, it should be concentrated in causes-of-death that are closely associated with pollution, such as respiratory diseases. Given this, I identify a set of cause-of-death categories that are not likely to be directly related to the effects of industrial pollution and then estimate the percentage increase in mortality in these categories associated with industrial pollution. This percentage increase in total mortality is then attributed to selection effects, while excess mortality above this level can be attributed to the direct effects of pollution. The cause-of-death results show that this excess mortality is driven by categories, such as respiratory diseases, that are strongly associated with pollution based on modern medical and public health literature. These results allow me to adjust the impact of pollution to account for selection while also addressing omitted variables concerns.

My baseline estimates focus on the earliest decade for which my data are available, 1851-1860. In this period, if I do not adjust for selection, I estimate that a one standard deviation (s.d.) increase in local pollution is associated with an increase in mortality of 6.6%. I can also adjust for selection effects using results from the cause-of-death analysis. This adjustment should be viewed as a conservative lower bound be cause it is based on the assumption that there are some cause-of-death categories where there are no direct pollution impacts. Any direct pollution impacts on these categories, such as impacts due to the effect of en utero exposure, will bias the selection-adjusted estimates downwards. After adjusting for selection, my lower-bound estimate of the impact of a one s.d. increase in pollution is 2.8-3.4% of total mortality. The actual impact of industrial pollution is likely to fall somewhere between the extremes represented by these adjusted and unadjusted values.

For comparison, the estimated impact of population density on mortality, which will reflect increases in disease transmission, residential pollution, and selection effects, is 7.8%. Thus, I find that the impact of pollution is at least one-third as large as all other factors associated with population density, and may be as large as 80% of the population density effect. Moreover, once I account for industrial pollution, the estimated coefficient on the relationship between population density and mortality in 1851-1860 falls by 20%, suggesting that industrial pollution accounted for one-fifth of the urban mortality penalty during this period.

Between 1851 and 1900, industrial pollution increased substantially. Using a long-difference approach, I analyze the impact of increasing levels of pollution driven by industrial coal use on mortality over this period. Without adjusting for selection effects I find that increasing industrial coal use raised mortality by 1.49-1.57 deaths per thousand over this period. With my conservative adjustment for selection effects, I estimate an increase in mortality of 0.65-0.69 per thousand. This period experienced a rapid reduction in mortality, with overall mortality falling by 4.4 per thousand due to the reduction in infectious disease mortality. These dramatic changes have obscured the increase in mortality due to rising industrial pollution during this period. However, my results suggest that over the 1851-1900 period, mortality would have dropped even faster – by 13-26% – if not for the increase in industrial pollution. In addition to helping us assess the impact of rising coal use over this period, the long-differences analysis also provides further evidence that the pollution effects I estimate are not driven by time-invariant omitted variables.

Finally, I assess the impact of pollution in one district on mortality in neighboring areas. This analysis takes advantage of the fact that the predominant wind direction across all of Britain is from the South and West to the North and East. Thus, for each major industrial area of the country, I compare mortality patterns in a set of downwind districts to mortality in upwind districts. My results show that mortality is higher in the downwind districts relative to the districts upwind of the same major industrial area, particularly for those districts downwind from larger industrial centers. This result is not reliant on a direct measure of industrial pollution and should be free of omitted variables concerns. I also find evidence of the selection of more polluting industries into districts that were already more polluted because of their downwind location.

These results provide a new perspective on the sources of mortality during this important period of history. While current work strongly emphasizes the role of the disease environment, this study suggest that the impact of pollution should be given more weight. The evidence I provide fills an important hole in the historical literature and connects our understanding of historical mortality patterns to the substantial modern literature documenting the health effects of pollution.

This paper builds on a relatively small set of recent studies investigating the impact of pollution during the 19th and 20th centuries. The closest is a study by Troesken & Clay (2011) looking at the evolution of pollution in London in the late 19th century. Using detailed time series data, they provide evidence that air pollution mixed with fog and held in place by anticyclone weather systems could have devastating health effects, but that these impacts appear to fall starting in the 1890s. Other work focusing on pollution in the 19th century includes Fouquet (2011, 2012). These recent contributions build on an older line of research debating the importance of pollution in 19th century cities ((Williamson, 1981b,a, 1982; Pollard, 1981)). For the mid-20th century, Barreca *et al.* (2014) show that the use of bituminous coal for home heating substantially increased mortality, while Clay *et al.* (2014) study the local impact of coal fired power plants. In addition, a number of studies investigate the health impacts of particular pollution events in the 20th century (Townsend (1950), Logan (1953), Greenburg *et al.* (1962), Ball (2015)). Relative to existing contributions, this study extends our knowledge by providing evidence for an earlier period over a broad set of locations while accounting for a number of potential identification issues. My focus on industrial pollution also complements existing work, which has largely focused on residential pollution sources.

The next section provides background information on the empirical setting. Section 3 introduces the data. The analysis is presented in Section 4. Section 5 concludes.

2 Empirical setting

2.1 Pollution in Victorian England

In England, pollution, particularly air pollution from coal burning, was a problem reaching back at least to the 17th century, when Evelyn published his Fumifugium (1661) decrying the smoke of London. But pollution became much more acute in the 19th century as industrialization took off and steam-driven factories expanded across the country.[6] In this study, much of the focus will be on pollution related to coal use. Coal was the main source of power during this period and is widely regarded as the most substantial pollution source.

Domestic coal consumption in Britain rose from 60 million tons in 1854 to over 180 million tons in 1900.[7] Most of this coal was burnt by industry; data from Mitchell (1988) show that in industry consumption accounted for 60-65% of domestic coal use over the study period.[8] In addition to being the largest user of coal, industry was also geographically agglomerated, leading to substantial variation in industrial coal use levels across locations.[9] Moreover, prior to electrification, power used in industry had to be generated on-site, so that most industrial coal use took place in urban areas. While industrial coal use tended to be less polluting, per ton, than other uses, the combination of concentrated production in urban locations and the high overall level of coal burnt suggests that industrial pollution was likely to have been an important contributor to urban pollution levels.[10]

Coal was not the only source of industrial pollution, nor was air pollution the only form that pollution took. Chemical industries such as alkali producers were particularly harmful, releasing hydrochloric acid into the air and ruining the nearby

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[6] Appendix A.1.1 describes estimated pollution levels in London starting in 1700 from Brimblecombe (1987) and Fouquet (2008).

[7] A graph is available in Appendix A.1.2. Data from Mitchell (1988).

[8] The 65% figure covers the industries included in my coal use measure, which span manufacturing and mining. Residential coal use accounted for roughly 25% of domestic coal consumption, while the remainder was used in utilities and transportation. See figure in Appendix A.1.2.

[9] It is worth noting that there was relatively little variation in the type of coal available across locations in England so we should not expect coal from different areas to imply substantially different levels of pollution. In contrast, in the U.S. some areas had large deposits of anthracite coal, which was cleaner than the bituminous coal available in other areas.

[10] Industrial use was cleaner relative to residential use because combustion was often more efficient and factory smoke-stacks deposited smoke at a higher altitude.

environment. These alternative pollution sources provide one motivation for the use of a second pollution measure not directly tied to coal use.

One unique feature of this historical setting is that, despite high levels of pollution, regulation of polluting industries was limited (Thorsheim (2006), Fouquet (2012)). This feature was due to a combination of the strong laissez faire ideology that dominated British policymaking during this period and the influence of local industrialists. While national acts regulating pollution were passed during this period, including the the Sanitary Act of 1866, the Public Health Act of 1875 and the Public Health (London) act of 1891, historical sources suggest that these measures had limited effectiveness, though there is some evidence that they began to influence outcomes starting around the turn of the century.[11]

2.2 Mortality in Victorian England

A good place to start understanding mortality in the second half of the 19th century is by looking at the main causes of death. This is done in Table 1 which is adapted from Woods (2000). The first two columns describe the number of deaths in England & Wales in different categories. The third and fourth columns describe the number of years of life that would have been gained had the cause of death been completely eliminated.[12] Some of the causes listed in Table 1 are specific to major diseases, such as tuberculosis, typhus, scarlet fever and measles. Many of the remaining deaths are gathered into general categories related to the systems that they affected, such as respiratory diseases, neurological diseases, cardiovascular diseases, and gastrointestinal diseases. These categories will include a variety of non-infectious causes of mortality and they may also include some infectious diseases. For example, the respiratory

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[11] One reason that these measures were largely ineffective is that the acts aimed at reducing pollution only "as far as practicable, having regard to the nature of the manufacturing trade" (Public Health Act of 1875). Thus, factory owners could avoid fines by claiming that the pollution was an unavoidable part of the production process. The acts also included substantial loopholes and imposed modest penalties on offenders. For example, Thorsheim (2006) (p. 114) reports that manufacturers were able to get around regulations targeting "black smoke" by claiming that their smoke was "merely brown". An exception was the Alkali Act of 1863, which was successful at cleaning up pollution in that industry by forcing Alkali producers to adopt a technology that dramatically reduced the emission of hydrogen chloride. Fouquet (2012) argues that this policy was successful because an inexpensive technology was available that allowed producers to capture almost all of the polluting emissions.

[12] This takes into account both the number of deaths associated with the cause and the age at which these deaths occurred.

disease category includes bronchitis, pneumonia, influenza, etc.

One important message from Table 1 is that, while the major infectious diseases were important causes of mortality, they are not the whole story. Other causes, particularly respiratory, cardiovascular, and neurological diseases were also important. All of these diseases are associated with airborne pollution.

Table 1 also shows that, while substantial progress was made in reducing mortality related to infectious diseases, mortality due to other causes, particularly respiratory diseases, were of increasing importance. While this may be partially due to the fact that people who were not dying of infections diseases would eventually die of something else, it is also consistent with increasing health costs due to rising pollution. Additional evidence presented in Appendix A.1.3 shows that mortality due to respiratory causes was rising in England in 1851-1870, before the large reductions in infectious disease mortality. This suggests that the increase in respiratory mortality was not a consequence of the fall of infectious disease mortality. Some other factor, such as increasing pollution, must have been driving up respiratory mortality rates during that period.

Table 1: Cause-specific mortality in England & Wales, 1861-1870 to 1891-1900

	Deaths by cause		Years of life gained if cause eliminated	
Cause	1861-1870	1891-1900	1861-1870	1891-1900
Respiratory diseases	719,601	1,044,719	4.66	5.82
Neurological diseases	595,747	426,224	3.75	3.45
Tuberculosis	529,425	426,224	3.56	2.16
Cardiovascular diseases	288,447	507,730	1.56	2.27
Diarrhea & Dysentery	230,201	226,143	1.45	0.33
Digestive diseases	209,744	365,484	1.17	1.92
Scarlet fever	207,867	48,290	1.57	0.31
Typhus	189,285	55,996	0.36	0.01
Violence	163,840	202,363	1.03	1.03
Whooping cough	112,800	115,670	0.81	0.74
Measles	94,099	126,841	0.70	0.83
Scrofula	93,529	189,782	0.63	1.15
Cancer	82,820	232,178	0.63	0.96
Other causes	1,277,095	1,368,714		

Data adapted from Woods (2000) p. 350.

3 Data

One unique feature of the historical setting I consider is that detailed mortality data are available from the Registrar General's reports. The data I use come from the decennial supplements and provide mortality averages by decade, starting in 1851.[13] The data were collected by an extensive system aimed at registering every birth, marriage, and death in England and Wales. The data that I use cover each decade from 1851-1900.[14]

Of the data collected by this system, those on mortality are considered to be the most accurate and comprehensive, the "shining star of the Victorian civil registration" (Woods (2000)). For every death, registration with the local official (the "Registrar") was required within five days, before the body could be legally disposed of. The Registrar was required to document the gender, age, and occupation of the deceased, together with the cause and age of death. While there is surely some measurement error in these data, relative to other sources available for the 19th century they provide a unique level of comprehensiveness, detail, and accuracy.[15]

The mortality data are reported at the district level and include information on cause and age of death, an important feature for this study. The Registrar General's office put a substantial amount of effort into improving the registration of causes of death in the 1840s. This included sending circulars to all registrars and medical professionals, constructing a standardized set of disease nosologies, and providing registrars and medical professionals with standardized blank cause-of-death certificates. Thus, while there is surely some measurement error in the cause-of-death reporting, the error rates are not likely to be too large, particularly in the broad cause-of-death categories used in this analysis.

In all of the analysis, I exclude districts within the borders of London, which was an outlier in many ways during this period. I also exclude a set of districts where there were substantial changes in the borders during a decade. Starting with 579 English districts, this excludes 36 districts in London and 16 other inconsistent districts, leaving a total of 527. When using data from multiple decades, I collapse

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[13] These data were obtained from Woods (1997) through the UK Data Archive.

[14] I stop in 1900 because after that point the cause of death categories change, making it impossible to construct consistent cause of death series beyond that point.

[15] Woods (2000) suggests that the statistics most prone to reporting error were live births, infant deaths and age. This is one motivation for focusing on all-age mortality in this study.

the data to a smaller set of districts in order to obtain more consistent geographic units.[16]

When using the mortality data, I generally adjust for differential mortality patterns at different ages to generate age-standardized mortality values. The formula is $MORT_d = \sum_g^G MR_{gd} PS_g$ where $MORT_d$ is the age-standardized mortality rate for district d, MR_{gd} is the raw mortality rate in age-group g in district d and PS_g is the share of population in age-group g in the country as a whole. Thus, this formula adjusts the district mortality rate to account for deviations in the age distribution of district residents from the national age distribution.

The second key ingredient for this study is a set of district-level pollution measures. My measures of local pollution are based on the industrial composition of districts. Data on the industrial composition is available from the Census of Population, which collected data on the occupation of each person in the country (a full census, not a sample). The resulting occupational categories, which include entries such as "Cotton textile worker" and "Boot and shoe maker," generally correspond closely to what we think of as industries. These data are reported for workers 20 years and older at the district level in 1851.[17] To obtain consistent series over time, I collapse the reported occupations into 26 industry categories covering nearly the entire private sector economy, including manufacturing, construction, services, and transportation, following Hanlon & Miscio (2014).[18]

The data on the industrial composition of districts are used to construct two measures of local pollution levels. The first measure is based on industry coal use, the main source of wide-spread industrial pollution during this period. To construct this measure, I use data on coal use per worker in each industry, denoted by θ_i, which is obtained from the 1907 Census of Production. I model coal use at the district level in a particular year t as made up of three components: local employment in industry i in district d and year t, the coal use intensity in that industry θ_i, and a time-varying term representing efficiency gains in coal use, which I denote ϕ_t. Putting

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[16] Specifically, I collapse any pair of district that experienced a border change resulting in the movement of more than 150 persons from one district to another.

[17] District-level occupation data are reported only in 1851 and 1861, after which reporting at this level of detail was discontinued.

[18] See Hanlon & Miscio (2014) and the online data appendix to that paper, available at `http://www.econ.ucla.edu/whanlon/appendices/hanlon_miscio_data_appendix.pdf`, for further details about the Census of Population Occupation data.

these together, the overall level of coal burnt in a district in a year is,

$$COAL_{dt} = \phi_t \sum_i \theta_i L_{id} = \phi_t EstCOAL_{dt} \,, \tag{1}$$

where L_{id} is employment in industry i in district d and $EstCOAL_{dt}$ is the estimate of district coal use available from the data. In the empirical analysis, the ϕ_t term will generally be absorbed by year fixed effects, while the data allow me to calculate $\sum_i \theta_i L_{id}$. This will be my preferred pollution measure. Implicit in this approach is the assumption that the *relative* coal intensity per worker across industries did not change substantially over time. In Appendix A.2.1, I provide evidence that this assumption is reasonable by comparing industry coal use intensity in 1907 and 1924.[19]

As a second measure of local pollution, I use a list of polluting industries constructed for the modern period by the Chinese government.[20] This list is consistent with qualitative historical evidence on the main polluting industries during the period I study and also corresponds fairly closely to the set of heavy coal-using industries based on the 1907 Census of Production. Given the set of dirty industries D, this measure of pollution in a district is the level of district employment in these "dirty" industries, $DIRTYemp_{ct} = \sum_{i \in D} L_{ict}$.

Table 2 describes the polluting industries included in the database, their national employment, coal use, coal use per worker, and an indicator for whether they are on the list of heavily polluting industries. Coal use per worker varies substantially across industries. The most intensive users, such as Earthenware & Bricks, Metal & Machinery, and Chemicals & Drugs, are often those that use coal to provide heat, for example to melt steel or fire bricks. Moderate coal-using industries such as Textiles, Mining, and Leather, use coal primarily to run engines for motive power. Industries such as Apparel, Tobacco, and Instruments & Jewelry, use very little coal per worker. Services, which are not on this list, are assumed to have a negligible amount of

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[19] Similar data are not available before 1907, so it is necessary to run this test on data after 1907. However, if anything we should expect larger changes between the 1907-1924 period than in the 1851-1907 period. This is because the sources of industrial power were fairly stable from 1851-1907, while the introduction of electricity means that we should see more changes in the 1907-1924 period. Thus, the fact that I find stable patterns in the 1907-1924 period suggests that the patterns were also likely to have been stable before 1907.

[20] Williamson (1981b) uses a somewhat similar methodology in which he focuses on only employment in mining and manufacturing. See Hanlon & Tian (2015) and the online appendix to that paper for further details.

coal use per worker. Also, I exclude public utilities when constructing the pollution measures. Some public utilities, particularly gas, were important coal users and did create local pollution. However, by converting coal into gas which was then pumped into cities, this industry may have actually decreased pollution in city centers. Thus, these industries are excluded because of their ambiguous effects on local pollution and local health. The last column of Table 2 shows that the list of heavily polluting industries corresponds fairly well to the list of coal-intensive industries.

Table 2: Industry employment in 1851, coal use, and pollution indicators

Industry	**National employment**	**Coal use per worker**	**Dirty industry?**
Earthenware, bricks, etc.	135,214	48.9	Yes
Metal and engine manufacturing	894,159	43.7	Yes
Chemical and drug manufacturing	61,442	40.1	Yes
Mining related	653,359	28.9	Yes
Oil, soap, etc. production	54,751	20.7	
Brewing and beverages	100,821	19.4	Yes
Leather, hair goods production	27,146	12.1	Yes
Food processing	220,860	12.0	
Textile production	1,066,735	10.1	Yes
Paper and publishing	226,894	9.7	Yes
Shipbuilding	169,770	6.1	
Wood furniture, etc., production	114,014	5.4	
Vehicle production	53,902	2.6	
Instruments, jewelry, etc.	43,296	2.0	
Apparel	243,968	1.6	
Construction	169,770	1.6	
Tobacco products	35,258	1.1	

Coal per worker values come from the 1907 Census of Production. The number of workers in the industry in 1851 come from the Census of Population Occupation reports.

The large variation in industry coal intensity described in Table 2 means that locations specializing in industries such as iron and steel production will have substantially higher overall coal use per worker than locations specializing in services, trade, or light manufacturing. This variation is illustrated in Table 3, which describes various pollution measures for a set of similarly-size districts. Coal use is substantially higher in districts like Stoke-upon-Trent, where the earthenware & pottery dominated the economy, and in mining areas such as Durham. Textile districts, such as Macclesfield and Norwich, show moderate amounts of coal use. Districts with economies based largely on trade or other services, such as Bristol and Bath, show lower levels of coal use. Similar, but not identical, patterns hold when pollution is measured using the list of heavily pollution industries.[21] The last two columns describe two alternative pollution measures that will be used for robustness exercises: the share of employment in heavily polluting industries, and the amount of coal use per worker.[22]

Table 3: Pollution indicators for a set of districts of similar size

District	**Pop.**	**Ln(Coal use)**	**Ln(Dirty emp.)**	**Dirty ind. employment share**	**Coal use per worker**
Stoke	64,625	13.16	9.34	0.58	26.41
Durham	63,113	12.44	8.99	0.46	14.33
Macclesfield	62,434	12.16	9.49	0.53	7.74
Norwich	71,317	11.94	8.85	0.26	5.66
Bristol	65,872	11.73	8.05	0.12	4.81
Bath	69,091	11.41	7.85	0.09	3.23

This table describes the characteristics of a selection of districts with similar populations but widely varying levels of local pollution. Stoke and Durham provide an example of heavy coal-using districts. Macclesfield and Norwich were specialized in light industries, particularly textiles. The economies of Bristol and Bath were based largely on trade and services, which produced little pollution.

In addition to the district-level industry employment data for 1851, I will also use national-level industry employment data for 1851-1891 from the same source.

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[21] There is a correspondence between the pollution measure based on coal use and that based on classification into heavily polluting industries, but the correlation is not perfect. This is due to the fact that simply classifying industries as polluting does not discriminate between heavy coal using industries such as metals, engineering, or mining, and moderate coal-using industries such as textiles.

[22] It is interesting to note how much the pattern in coal use per worker differs from the log of coal use, for example between Durham and Macclesfield. This is due in part to substantial differences in labor force participation. Female and child labor force participation were particularly high in textile areas and lower in economies based on engineering, steel or mining. This means that, even in districts with the same population, there is substantial variation in the number of workers, which affects the denominator in the coal use per worker values.

Combining the district-level variation from the 1851 data with industry growth rates for 1851-1891 from the national data, I construct estimated district employment and pollution levels for the years 1861-1891.[23]

Information on district population and population density were collected from the Registrar General's reports. Summary statistics for these and other key variables for the 1851-1860 period are available in Table 4.

Table 4: Summary statistics for key variables

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Mortality (age-std per 1000)	527	19.65	3.21	12.71	37.28
Ln(Coal use)	527	10.23	1.09	7.30	13.76
Ln(Dirty employment)	527	6.68	1.29	3.30	10.71
Ln(Pop. density) (per acre)	527	-0.75	1.23	-3.54	4.78
Ln(Dist. pop)	527	9.96	0.69	7.82	12.48
Water serv. emp. (per 10,000 pop)	527	0.92	2.04	0.00	28.57
Medical serv. emp. (per 10,000 pop)	527	39.50	19.86	7.42	131.86

I have constructed additional control variables for several factors that may have affected health during this period. Because of the importance of clean water in influencing mortality during this period, I construct a control for the water services provided in each district. This variable is based on the number of persons employed in providing water services, either public or private, per 10,000 of district population, based on occupation data from the Census of Population. Similarly, I construct a variable representing the number of persons employed in medical occupations, per 10,000 of district population.[24]

I also construct two variables related to seaports: an identifier for whether the district contains a seaport and the tonnage of shipping that passed through the port. This second variable is included because of the importance of trade in spreading

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[23] This approach is somewhat similar to Bartik (1991) except that I do not have data for each district across all periods. Thus, when I calculate the national industry growth rate to be applied to a district, it is not possible to remove that district from the data. Given that there are over 500 districts, and that the national economy is not dominated by a few large districts (recall that London is excluded from the data set), this is not likely to be a major source of bias.

[24] The occupations included in this category are physicians, surgeons, other medical men, dentists, nurses (not domestic) and midwives.

disease. Both of these are based on information from the Annual Statement of Trade and Navigation for 1865.

4 Analysis

This section begins with a discussion of the main issues that must be addressed in the analysis. Next, I present some baseline cross-sectional results followed by an analysis of selection issues using data on causes-of-death. I then use long-difference regression results in order to assess how changing pollution levels from 1851-1900 affected mortality. Finally, I analyze the spillover of pollution into districts downwind of the major industrial centers.

4.1 Discussion of analysis issues

Selection: The selection of less healthy populations into more polluted areas is an important identification concern. This study uses two types of evidence to address this issue. First, I use results on cause-of-death (Section 4.3). Specifically, I look at the impact of pollution on cause-of-death categories that are unlikely to be directly related to pollution. Assuming that less healthy populations have higher mortality across most or all causes-of-death, increases in mortality in categories unrelated to pollution can provide a measure of the size of the selection effect. Excess mortality above this level can then be attributed to the direct impact of pollution. This provides a lower bound on the impact of pollution because it will be biased downwards if health effects resulting from pollution make people more susceptible to all diseases. For additional evidence, I draw on data that report cause-of-death and location for people in two occupational categories, innkeepers and general laborers. To the extent that these categories reflect income and class, results obtained across workers within these categories should be largely free of selection effects.

Omitted variables: Another threat to identification in this study is that there may be omitted variables that are correlated with the the local presence of polluting industries and also affect mortality. This study offers several approaches for addressing this concern. Examining the relationship between pollution and causes-of-death provides one way to address omitted variables concerns (Section 4.3). In particular, unless the omitted variables specifically affect mortality in categories associated with airborne pollution, the cause-of-death analysis will deal with them. Further evidence against omitted variables is provided by the long-difference regressions (Section 4.4). This will deal with any omitted variables that are fixed over time. Finally, I will look at the impact of pollution on districts that are downwind of major industrial centers, compared to districts just upwind of the same area. Unless the omitted variables are somehow correlated with wind patterns, they should not affect these results. In addition to these approaches, I have also constructed control variables that can be helpful in dealing with some of the most obvious potential concerns.

Acute vs. chronic effects: Pollution can have both chronic effects, such as lung diseases caused by long-term exposure to air pollution, and acute effects, such as heart attacks related to a particularly bad pollution day.[25] The mortality patterns documented in this study will reflect both of these channels. Separating the chronic and acute effects of pollution is an important direction for future research, but is beyond the scope of this study.

Migration: Migration and travel can potentially affect the results if people are exposed to pollution in one location but die in another. In general, migration will bias the estimated impact of pollution towards zero. To see why, suppose that regardless of the location of exposure, the location of death is random. In that case I should estimate no relationship between pollution and mortality. In contrast, if the location of death matches the location of exposure exactly then there will be no bias in the estimated effects. In reality, my data will fall somewhere in between, implying that the estimated impact of pollution will be biased towards zero. As a results, the estimates described in this study are likely to understate the true impact of pollution on mortality. A related issue is that people from healthy areas may travel into a more polluted area, die as the result of short-term pollution exposure, and be counted in the mortality figures for that district. This would be captured in the estimated relationship between pollution and mortality, and rightly so, as it reflects the acute effects of pollution.

Income: If more polluting industries paid lower wages, we may be concerned that the mortality patterns we observe are driven by income effects. However, evidence on wages from Bowley (1972) suggests that the most polluting industries, such as iron

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[25] A recent paper highlighting the acute effects of air pollution is Schlenker & Walker (2014).

production and mining, were also high-wage industries (see Appendix A.2.3). Furthermore, evidence from (Williamson, 1981b, 1982) and Hanlon (2014) suggests that, even within occupations, workers were compensated for living in more polluted locations with wages that were higher relative to the local cost of living. This evidences suggests that, if anything, income effects will work against finding a substantial impact of pollution on mortality. Finally, note that the cause-of-death analysis used to deal with selection concerns will also address selection of lower-income workers into more polluted areas.

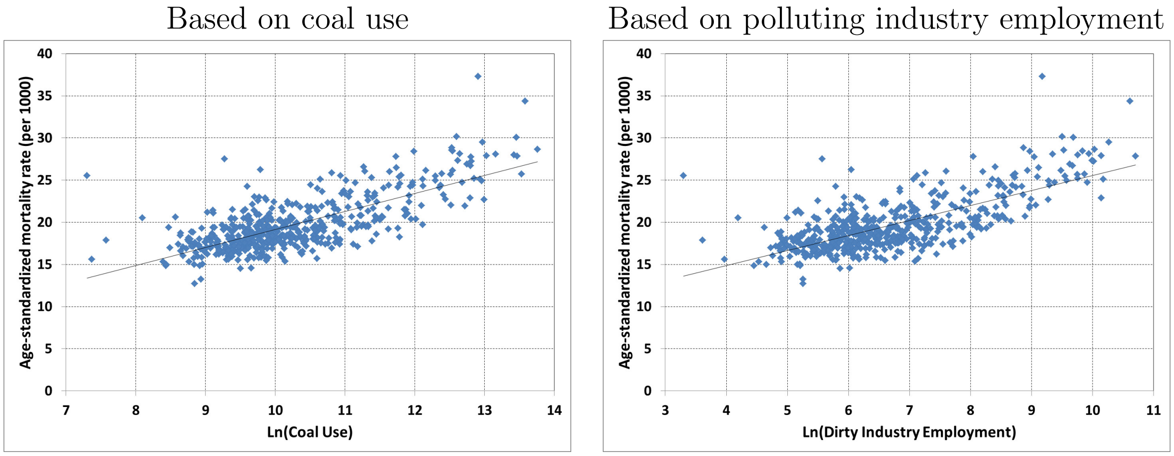
On-the-job mortality: We may be concerned that the results are picking up other effects of industrial composition on mortality, such as on-the-job accidents. The cause-of-death results can address this concern, since they explicitly separate out on-the-job accidents, which are included in the "Violence" category. A related issue is whether pollution exposure occurs on-the-job or elsewhere. In this study I do not seek to differentiate between these two types of exposure to pollution, though some evidence, such as mortality for the very young, will reflect only exposure outside of the workplace.

Residential pollution: Pollution from residential sources made a substantial contribution to overall pollution during this period, particularly in London. However, the results in this study are focused only on industrial pollution and should not be interpreted as including the impact of residential pollution as well. The impact of residential pollution will largely be captured by control variables, particularly population density, but also the regional controls, which will capture a variety of factors that can influence residential pollution levels including weather and local coal prices.

4.2 Baseline cross-sectional results

The analysis begins, in Figure 2, by looking at the univariate relationship between mortality and each of the two pollution measures. For both pollution measures there is a clear positive relationship to mortality. Ex ante it is not obvious what functional form we should expect for the relationship between the pollution measures and mortality. Figure 2 makes it clear that, when taking the natural log of the pollution measure, the relationship to mortality is close to linear. This finding is supported by previous results suggesting a concave relationship between pollution exposure and mortality (Pope III *et al.* (2011), Clay *et al.* (2014)). Thus, my main results will use the log of coal use or dirty industry employment as the pollution measure, though I will investigate the robustness of my results to other alternatives.

Figure 2: Pollution and mortality in England in 1851-1860


Based on coal use

Based on polluting industry employment

The pollution measures are based on the industrial composition of the districts in 1851. The mortality rate is age-standardized and calculated using data from 1851-1860.

Next, I undertake some simple cross-sectional regressions using pollution measures based on the industrial composition of districts in 1851 and mortality data for 1851-1860. The regression specifications is,

$$MORT_d = \beta_0 + \beta_1 \ln(DENSITY_d) + \beta_2 \ln(POP_d) + \beta_3 \ln(POLL_d) + X_d\Lambda + R_d + \epsilon_d\,, \qquad (2)$$

where $MORT_d$ is the average age-standardized mortality rate over a decade in thousands of people per year in district d, $DENSITY_d$ is the population density, POP_d is district population, $POLL_d$ is one of the measures of local pollution, X_d is a vector of control variables, and R_d is a full set of region indicator variables.[26] Because spatial correlation may be an issue here, I allow correlated standard errors between any pair of districts within a certain distance (50km) of each other, following Conley (1999).[27]

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[26] The regions are Southeast, Southwest, East, South Midlands, West Midlands, North Midlands, Northwest, Yorkshire, and North.

[27] I implement this using code provided by Hsiang (2010). The latitude and longitude of each

One issue that will be important in this study is the possibility that there may be a lag between the time at which pollution took place and when the effect on mortality appeared. In the cross-sectional regressions presented in this subsection, this issue can largely be ignored because both pollution and mortality levels are fairly stable over time. However, this issue will be critical later, when I turn to regressions that are identified using variation over time.

In relating Eq. 2 to the coal use measure in Eq. 1, note that in the cross-section the ϕ_t term from Eq. 1 will simply be a constant, and, because I am working in logs, it will be incorporated as part of the constant term. Put another way, in cross-sectional regressions I do not need to worry about changes in the efficiency of coal use over time conditional on the relative coal use intensity of industries remaining fairly constant over time (as suggested by the analysis in Appendix A.2.1).

Table 5 presents the baseline cross-sectional results. The first four columns look separately at population density, district population, and the two pollution measures. Individually each of these has a positive and statistically significant relationship to mortality. Columns 5 and 6 combine the population and population density variables with one of the pollution measures. In these regressions, population density and the pollution measures continue to have a positive and statistically significant relationship to mortality.[28]

The control variables included in these regression are of some interest in themselves. Both employment in water provision and employment in medical services are negatively related to mortality once population density is accounted for. This is comforting, but it should not be interpreted as a causal effect, since it may simply reflect sorting or omitted variables. The two seaport variables reveal that small seaports may have been healthy places to live, but increased trade had a clear positive relationship to mortality.[29]

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district were collected by hand. These generally correspond to the center of the town that the district was named after, which is generally also the main population and administrative center. In some cases no such town exists, and for those we chose a location that was close to the geographic center of the district.

[28] It is interesting that, once population density is included, district population is negatively related to mortality, though this relationship is often statistically insignificant. One potential cause for this negative relationship is that, once density is controlled for, greater district population may be reflecting variation in average income levels across districts.

[29] Perhaps the most unhealthy place to live in all of England was the bustling port of Liverpool.

Table 5: Cross-sectional regressions for 1851-1860

	DV: Age-standardized mortality					
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Pop. Density)	2.045***				1.614***	1.647***
	(0.127)				(0.0953)	(0.0878)
Ln(District pop.)		2.700***			-0.943***	-0.381
		(0.389)			(0.305)	(0.238)
Ln(Coal use)			2.049***		1.280***	
			(0.204)		(0.253)	
Ln(Dirty emp.)				1.741***		0.792***
				(0.180)		(0.156)
Water service emp.	-0.0238	-0.000988	-0.0308	-0.000917	-0.0514	-0.0448
	(0.0572)	(0.0724)	(0.0664)	(0.0671)	(0.0565)	(0.0565)
Medical service emp.	-0.0224***	0.0129	0.0217***	0.0267***	-0.0101*	-0.0106*
	(0.00736)	(0.00812)	(0.00564)	(0.00559)	(0.00524)	(0.00544)
Seaport tonnage	1.216***	3.687***	4.230***	4.754***	1.978***	2.002***
	(0.418)	(0.447)	(0.336)	(0.321)	(0.351)	(0.345)
Seaport indicator	-0.131	-0.355	-0.280	-0.123	-0.190	-0.177
	(0.267)	(0.289)	(0.285)	(0.284)	(0.259)	(0.256)
Constant	22.13***	-8.097**	-2.065	7.076***	17.87***	20.09***
	(0.499)	(3.512)	(1.931)	(1.137)	(2.273)	(2.313)
Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	527	527	527	527	527	527
R-squared	0.741	0.541	0.626	0.618	0.767	0.765

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851.

Using these results, together with the summary statistics from Table 4, it is possible to get an idea of the relative importance of pollution. Using the pollution measure based on coal use (Column 5), the impact of a one standard deviation increase in the log of polluting industry employment (1.09), which represents roughly the difference between an industrial area like Stoke-upon-Trent and similarly-sized less industrial district such as Norwich, is an increase in mortality of 1.40 per thousand or 7.1% of overall mortality. The results in Table 5 also reveal the importance of industrial pollution for explaining the urban mortality penalty. Comparing the results for the population density variable in Columns 5 and 6 to the results in Column 1 suggests that the estimated mortality penalty in more dense areas decreases by roughly 20%. This implies that industrial pollution explains roughly one-fifth of the urban mortality penalty in 1851-1860. In Section 4.3, I consider how these estimates are affected when I adjust for the selection of less healthy individuals into more polluted areas. However, before doing so I want to establish the stability of the estimated association between pollution and mortality.

In the regressions described in Table 5, each district is treated as one observation with equal weight, regardless of district size. Alternatively, we may want to put greater weight on districts with larger populations. Appendix A.3.1 provides regression results obtained while weighting districts based on their average population size over the decade. Weighting has relatively little impact on the results, though the magnitude of the estimated pollution effect does increase somewhat. Given the similarity between weighted and unweighted regression results, for the remainder of this study I present only results from unweighted regressions.

A potential concern with the results in Table 5 is that they may be dependent on choices about the functional forms used for the pollution variables. Table 6 considers the estimated impacts based on a variety of alternative functional forms for the pollution variables.[30] Column 1 uses coal per worker. Column 2 uses the share of employment in heavily polluting industries. Column 3 uses the log of coal per acre. Column 4 uses the log of dirty industry employment per acre. Finally, in Column 5 I include, separately, the log of employment in heavily polluting industries and in all other industries ("Clean emp.").[31] The basic results do not appear to be sensitive to any of these alternative functional forms. In Column 5, it is comforting to see that employment in clean industries is associated with reduced mortality, while employment in dirty industries increases mortality.

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[30] Summary statistics for these alternative explanatory variables are available in the Appendix.

[31] Clean and dirty employment does not sum to district population because there is a substantial unemployed population in each district, including children, elderly, and non-workers.

Table 6: Robustness to alternative functional forms

	DV: Age-standardized mortality				
	(1)	(2)	(3)	(4)	(5)
Coal per worker	0.165***				
	(0.0332)				
Dirty ind. emp. shr.		5.618***			
		(0.740)			
Ln(Coal use/acre)			1.280***		
			(0.253)		
Ln(Dirty ind. emp/acre)				0.792***	
				(0.156)	
Ln(Dirty ind. emp.)					0.514**
					(0.208)
Ln(Clean ind. emp.)					-1.419**
					(0.681)
Ln(Pop. Density)	1.646***	1.549***	0.334	0.855***	1.625***
	(0.0998)	(0.0887)	(0.291)	(0.177)	(0.0846)
Ln(District pop.)	0.320	0.301	0.337	0.411*	1.201
	(0.228)	(0.216)	(0.214)	(0.223)	(0.773)
Region controls	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	527	527	527	527	527
R-squared	0.767	0.779	0.767	0.765	0.769

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. Other control variables include employment in water services per 10,000 population in 1851, employment in medical services per 10,000 population in 1851, a seaport indicator variable, and seaport tonnage in 1865.

It is also possible to look at how these patterns evolved over time. This is done in Table 7, which uses data from a standardized set of districts (to account for changes in district boundaries over time) and runs cross-sectional regressions for each decade from 1851-1900.[32] In these regressions the district population and density variables are adjusted for each decade, but the pollution measures and other control variables are fixed across all periods.[33] For the pollution measures this seems reasonable given the substantial inertia in local industrial structure, but it may be less reasonable for the control variables. I report only results obtained using the pollution measure based

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[32] When these collapsed districts span multiple counties, they are assigned to the county in which most of the original districts lie.

[33] An exception is the density measure for 1891-1900. In that decade I use the density measure from 1881-1890 because I do not have data on population density at the district level in 1891-1900.

on coal use, but similar results are obtained when measuring pollution based on the list of heavily polluting industries.

The results in Table 7 show that pollution had a clear positive impact on mortality in all decades. This relationship was fairly stable from 1851-1880, and declined after 1881.[34] This pattern is similar to the results of Troesken & Clay (2011), who document declines in the number of fog days in London starting around 1891. This pattern is also consistent with the existence of an Environmental Kuznets Curve.

Table 7: Regressions for each decade from 1851-1900

	DV: Age-standardized mortality				
	1851-1860	**1861-1870**	**1871-1880**	**1881-1890**	**1891-1900**
Ln(Coal use)	1.253***	1.076***	1.262***	0.893***	0.744***
	(0.283)	(0.288)	(0.215)	(0.178)	(0.125)
Ln(Pop. Density)	1.569***	1.541***	1.637***	1.307***	1.305***
	(0.179)	(0.157)	(0.179)	(0.140)	(0.139)
Ln(District pop.)	-0.916***	-0.527	-0.932***	-0.490**	-0.256*
	(0.348)	(0.387)	(0.346)	(0.234)	(0.146)
Region controls	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	321	321	321	321	321
R-squared	0.731	0.781	0.807	0.817	0.825

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other.When collapsing districts for consistency I use the mean latitude and longitude across original districts as the location for the new district. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. Other control variables include employment in water services per 10,000 population in 1851, employment in medical services per 10,000 population in 1851, a seaport indicator variable, and seaport tonnage in 1865.

Additional analysis, in Appendix A.3.2, considers the pattern of pollution effects across age categories. These results show that the impact of pollution is pronounced for children and for adults over age 45. There is also a small but statistically significant effect on young adults in the 15-24 age group. The impacts on children are driven primarily by respiratory and neurological diseases, while higher levels of mortality

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[34] Population density also increased mortality, but this effect also declined after 1881. The pattern of decline after 1881 reflects the gains made against infectious disease mortality. Water services and medical services are negatively related to mortality in all years, while trade (seaport tonnage) increased mortality in all years. These relationships are stable, but should be interpreted with some caution because the controls are based on 1851 data.

among adults over age 45 are associated with respiratory and digestive diseases. There is also some evidence that pollution increases mortality due to tuberculosis, which affected adults starting around age 15.

4.3 Selection effects and causes-of-death

Analyzing the cause of death can help address the possibility that the results above are be driven by selection of less healthy people into more polluted areas or by omitted variables. The basic idea behind my approach is that, if the overall mortality patterns are driven by selection, then we should observe higher mortality across many cause-of-death categories in more polluted areas. In contrast, if pollution effects are higher in the cause-of-death categories most closely associated with pollution (identified based on the modern medical and public health literature), then this can be interpreted as reflecting the direct effect of pollution on mortality.

To quantify the impact of selection on the results, I begin with,

$$\ln(MORT_d^{CAT}) = b_0 + b_1 \ln(DENSITY_d) + b_2 \ln(POP_d) + b_3 \ln(POLL_d) + X_d \Lambda + R_d + \epsilon_d\,, \quad (3)$$

where the CAT superscript indicates mortality in a set of cause-of-death categories.

The set of cause-of-death categories that are less related to pollution, which I will label "NPR" (not pollution related), will be particularly important in this analysis. I offer two alternatives for the NPR categories. The first set, which I refer to as NPR1, is composed of mortality due to five major non-respiratory infectious diseases: Cholera (which includes diarrhea and dysentery), Diphtheria, Scarlet Fever, Smallpox, and Typhus. The second set, NPR2, is composed of the diseases in NPR1, plus mortality related to kidneys, the urinary system and generative organs.

The first two columns of Table 8 describe the estimated percentage change in mortality in the NPR categories using the coal use measure. These results suggest that a one s.d. increase in coal use (1.09) was associated with an increase in mortality in the NPR categories by 3.9-4.5% (though this effect is not statistically significant). To adjust for potential selection effects, I interpret this increase as indicative of the increase across all categories due to selection of poorer or less healthy individuals into more polluted areas. Any additional impact of pollution on mortality beyond this 3.9-4.5% increase is then attributed to the direct effect of pollution. Note that if any direct effects of pollution are reflected in the impact on the NPR categories, this will bias down my selection-adjusted estimates of the direct impact of pollution. In reality, there are numerous reasons to think that pollution may increase mortality in these cause of death categories, starting with the negative long-term effects of en utero exposure to pollution.[35] This is why the selection-adjusted estimates offered below should be though of as conservative lower-bounds that are likely to understate the true impact of pollution on mortality. Column 3 of Table 8 presents results for all mortality categories. This suggests that a one s.d. increase in industrial pollution from coal burning is associated with an increase in overall mortality of 7.5%. If we attribute 3.9-4.5% of this to selection effects, this suggests that the remaining direct effect of a one s.d. increase in industrial pollution is associated with an increase in overall mortality of 3.0-3.6% or 0.59-0.71 deaths per thousand. This method assigns a large fraction of the pollution-mortality relationship, 52-60%, to selection. However, even allowing for such a large selection effect, I still find that industrial pollution had important mortality effects. Applying the same exercise using the alternative pollution measure based on dirty industry employment suggests a lower bound on the direct effect of pollution equal to 3.9-4.3% of total mortality (see Appendix A.3.3).

Columns 5 restricts attention to a broad set of causes-of-death that are associated with the effects of airborne pollution. This includes respiratory diseases, cardiovascular and circulatory diseases, cancer, digestive diseases, diseases of the nervous system, death in childbirth, and two infectious diseases of the respiratory system, measles and tuberculosis.[36] For these categories, the estimated impact of industrial pollution is greater than the impact estimated across all causes-of-death. Finally, Column 6 presents results for only mortality related to the respiratory system, which

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[35] See, e.g., Chay & Greenstone (2003) and Currie & Neidell (2005).

[36] Airborne pollution is most strongly associated with respiratory diseases, cardiovascular diseases, and cancer. Rückerl *et al.* (2011) provides a recent review of this literature. Airborne pollution can also affect the digestive system because inhaled pollution can be swallowed. Air pollution has been linked to diseases of the nervous system, including stroke. Another channel for nervous system effects is that pollution from coal-burning is a major source of lead pollution, which particularly affects children. According the the EPA, coal burning remains one of the largest course of lead pollution in the U.S. A few studies link air pollution to pre-eclampsia, a major risk factor for death in childbirth (e.g., Wu *et al.* (2009), Vinikoor-Imler *et al.* (2012), Lee *et al.* (2013), and Pereira *et al.* (2013)). Finally, studies by Creswell *et al.* (2011) and Chang *et al.* (2001) link airborne pollution to tuberculosis.

is the category most closely associated with the effects of air pollution. Here we see even larger estimated impacts; a one s.d. increase in industrial pollution is associated with an increase of 14% in mortality due to diseases of the respiratory system (bronchitis, pneumonia, etc.). The fact that the estimated impact of industrial pollution increases as I focus on cause-of-death categories that are more closely associated with the effects of pollution provides further evidence that the estimated effects are reflecting the direct impact of pollution on mortality.

I have also considered, in Appendix A.3.4, the role of pollution and selection in influencing mortality among children 5 years and younger. This is an interesting group to study because of the high mortality rates experienced by children and the fact that this group has been widely studied in the modern pollution literature.[37] This analysis shows that a one s.d. increase in district coal use increased child mortality by 6.9% without adjusting for selection, or 5.7-5.9% when adjusting for selection using the same methodology applied to all-age mortality above.

Further evidence relevant for assessing selection effects is available from reports providing cause-of-death for workers within particular occupation categories and geographic divisions. Because occupation categories are a good proxy for income and class, mortality variation within an occupation should be less vulnerable to the influence of selection. Data on mortality by cause within occupation groups and across locations are generally not available in the period I study. However, I have found data of this type in a special report included in the Supplement to the Registrar General's 65th Annual Report (1891-1900) for two common occupations, General Laborers and Innkeepers. The data are from 1900-1902 and the cause-of-death categories are more detailed than those available in the 19th century data. The report breaks down mortality separately for the industrial districts and England & Wales as a whole. These data allow me to look at how the relative importance of different causes of death vary between the industrial districts and the rest of the country for workers within a particular occupation.

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[37] The modern literature often focuses on infant mortality. I consider mortality for all children 5 years and younger, rather than infant mortality, because of concerns about measurement error in the infant mortality counts.

Table 8: Analyzing selection effects using cause-of-death

	DV: Ln(Age-standardized mortality)				
Category:	NPR1 (1)	NPR2 (2)	Total mortality (3)	Pollution related (4)	Respiratory only (5)
Ln(Coal use)	0.0410	0.0357	0.0690***	0.0857***	0.130***
	(0.0263)	(0.0234)	(0.0124)	(0.0231)	(0.0504)
Ln(Pop. Density)	0.133***	0.132***	0.0730***	0.0764***	0.137***
	(0.0154)	(0.0130)	(0.00470)	(0.00626)	(0.0144)
Ln(District pop.)	0.0590	0.0494	-0.0512***	-0.0761***	-0.0861
	(0.0473)	(0.0384)	(0.0147)	(0.0260)	(0.0587)
Water service emp.	0.000389	0.00102	-0.00234	-0.000502	0.00527
	(0.00604)	(0.00538)	(0.00285)	(0.00242)	(0.00364)
Medical service emp.	-0.000358	-0.000193	-0.000311	0.000119	-0.000415
	(0.000820)	(0.000732)	(0.000233)	(0.000341)	(0.000829)
Seaport tonnage	0.000859	-0.00174	0.0484***	0.0467***	0.0946***
	(0.0436)	(0.0389)	(0.0105)	(0.0146)	(0.0325)
Seaport indicator	0.0392	0.0427	-0.00293	-0.0245	-0.0527*
	(0.0447)	(0.0408)	(0.0132)	(0.0168)	(0.0304)
Constant	0.0192	0.266	2.857***	2.195***	0.472
	(0.397)	(0.326)	(0.113)	(0.147)	(0.328)
Region controls	Yes	Yes	Yes	Yes	Yes
Observations	527	527	527	527	527
R-squared	0.546	0.567	0.739	0.654	0.581

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. The NPR1 causes in Column 1 contains five infectious diseases that do not primarily affect the respiratory system: Cholera (which includes diarrhea), Diphtheria, Scarlet Fever, Smallpox, and Typhus. The NPR2 causes in Column 2 contains the NPR1 categories plus mortality related to kidneys, the urinary system, and the generative organs. Column 3 presents results for overall mortality. Column 4 presents results for mortality from a set of cause-of-death commonly associated with pollution: respiratory diseases, cardiovascular and circulatory diseases, cancer, digestive diseases, diseases of the nervous system, death in childbirth, and two infectious diseases of the respiratory system, measles and tuberculosis. Column 5 looks only at respiratory system mortality, the category most closely associated with the effects of air pollution.

In Figure 3, I calculate the share of overall mortality for each cause of death in these data, and then plot the difference between the share in the industrial districts and the share in England & Wales as a whole, for General Laborers and Innkeepers.[38] This figure shows us that within these occupational groups, two respiratory-related causes of death – bronchitis and pneumonia – accounted for a much larger share of

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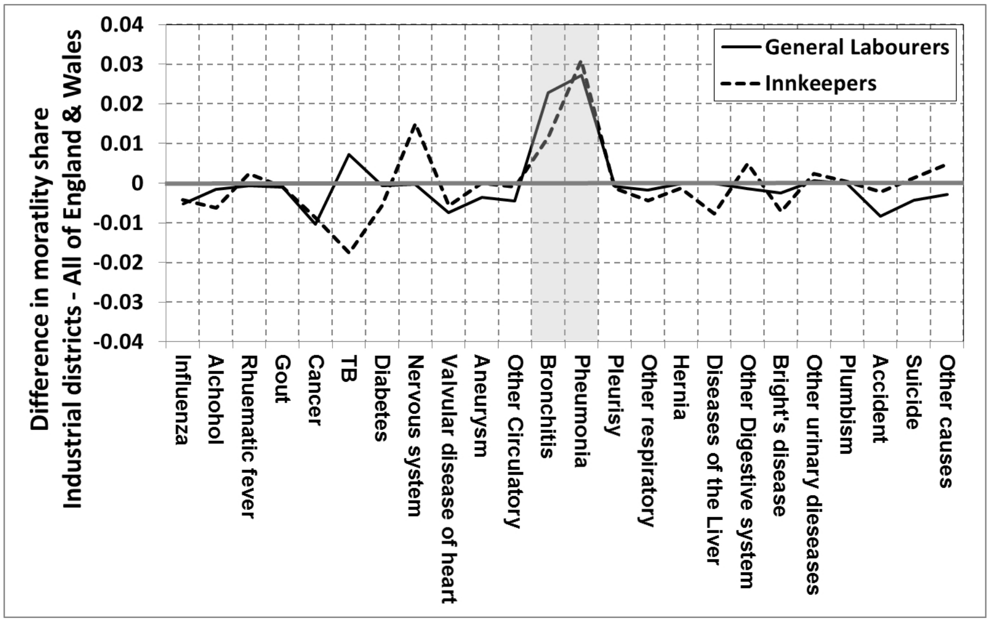
[38] Additional graphs are available in Appendix A.3.5.

overall mortality in the industrial districts of the country than in the country as a whole. This shows that, even for workers with the same occupation, there is evidence that pollution affected mortality in the industrial areas.

Figure 3: Relative importance of causes of death within two occupations



Another potential concern in this analysis is that polluting industries may be associated with higher on-the-job mortality due to accidents or injuries. It would be misleading to include these in the mortality associated with pollution. The cause-of-death data can help me deal with this because they separate out deaths from violent causes, which includes accidents and injuries. Table 9 presents regression results describing the relationship between the level of local coal use and these violent deaths. These regressions include the full set of control variables, but for brevity I report only the pollution and population density results. These suggest that a one s.d. increase in local coal use is associated with an increase in violent deaths of 12.9% or 0.098 per thousand. Without the selection adjustment, the impact of a one s.d. increase in industrial pollution on total mortality was estimated to be 1.40 (based on results from Column 5 of Table 5). Subtracting from this the impact of pollution on violent deaths, we are left with an impact of 1.30 per thousand, or 6.6% of total mortality.

When adjusting for selection, the impact of industrial pollution on total mortality after adjusting for selection effects (using the local coal use measure) was equal to 0.59-0.71 per thousand. Subtracting from this the the excess mortality in the violence category after adjusting that impact for selection, the remaining effect of pollution is equal to 0.55-0.66 per thousand, or 2.8-3.4% of overall mortality. This range should be viewed as a conservative lower-bound estimate of the impact of increased pollution on mortality in the 1851-1860 period.

Table 9: Estimated relationship between pollution and violent deaths

	DV: Age-std. mortality	**DV: Ln(Age-std. mortality)**
	(1)	(2)
Ln(Coal use)	0.0979***	0.129***
	(0.0181)	(0.0286)
Ln(Pop. Density)	0.0279*	0.0310
	(0.0150)	(0.0211)
Ln(District pop.)	-0.0875**	-0.0978*
	(0.0352)	(0.0542)
Region effects	Yes	Yes
Control vars.	Yes	Yes
Observations	527	527
R-squared	0.341	0.334

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. These additional control variables included are log district population, water service employment, medical service employment, a seaport indicator variable and seaport tonnage.

4.4 Long-difference results

Next, I consider results based on long-difference regressions. These results can help us assess the impact of increasing pollution on mortality over the 1851-1900 period and provide further confidence that time-invariant omitted variables are not driving the estimated pollution effects. Because district-level industry data are only available in 1851, the pollution measures for some year t in this analysis are calculated by multiplying district employment in an industry in 1851 times the national growth rate of the industry from 1851 to t to obtain predicted district industry employment in year t. This is then multiplied by industry coal use per worker and summed across industries to obtain predicted district coal use in period t, similar to Bartik (1991).

We have to be careful when using time variation to identify the effects of pollution on mortality because the effects of pollution build up over time. Thus, pollution levels in the past may influence mortality today, perhaps even more strongly than current pollution. Given this concern, my preferred approach is to use a long-difference,

$$\begin{aligned} MORT_{dt} - MORT_{dt-\delta} &= \alpha_0 + \alpha_1 \left[\ln(POP_{dt-\tau}) - \ln(POP_{t-\tau-\delta})\right] \\ &+ \alpha_2 \left[\ln(POLL_{dt-\tau}) - \ln(POLL_{dt-\tau-\delta})\right] + e_{dt} \, , \end{aligned} \tag{4}$$

where δ denotes the size of the long-difference.[39] This specification reveals two potential issues. First, the effect of pollution may take some time to impact mortality levels. This feature is reflected in the term τ in Eq. 4. This lag will be important when identifying off of time variation, so I will explore possibilities ranging from zero to two decades.

A more important concern is that the impact of pollution in one period may stretch far enough into the future that $\ln(POLL_{dt-\tau-\delta})$ influences $MORT_{dt}$. Any relationship of this type will bias α_2 downwards. The best approach for addressing this concern is to take as long a difference as possible. Because my data span several decades, I am able to take differences over as much as 40 years, allowing me to substantially reduce this concern.

Another potential concern in this specification is that the change in district population may be partially driven by changes in local pollution levels (as shown in Hanlon (2014)). To address this, I calculate the expected growth in district employment by multiplying initial industry employment levels in a district by the national industry growth rate, and then summing over industries. This is included in place of actual district population in some specifications.[40]

Because these regressions use time variation, changes in the efficiency of coal use over time now become an important concern. To see why, I substitute Eq. 1 into Eq. 4, to obtain,

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[39] Note that $DENSITY_{dt}$ is not included in this regression because, with the land area of districts held fixed, changes in density will be captured by changes in district population.

[40] I have also explored using expected district employment as an instrument for actual district population in 2SLS regressions. This delivers similar results to those described in Table 10.

$$\begin{aligned} MORT_{dt} - MORT_{dt-\delta} &= \alpha_0 + \alpha_1 \left[\ln(POP_{dt-\tau}) - \ln(POP_{t-\tau-\delta})\right] \\ &+ \alpha_2 \left[\ln(EstCOAL_{dt-\tau}) - \ln(EstCOAL_{dt-\tau-\delta})\right] \qquad (5) \\ &+ \alpha_2 \left[\ln(\phi_{t-\tau}) - \ln(\phi_{t-\tau-\delta})\right] + e_{dt}\,. \end{aligned}$$

If I run this regression without including the $[\ln(\phi_{t-\tau}) - \ln(\phi_{t-\tau-\delta})]$ term, then this term will be incorporated into the constant. As a result, the estimated value of α_2 will not reflect efficiency improvements in coal use per worker over time. In that case, α_2 will provide an estimate of the impact of coal use over the period *in the absence of any efficiency improvements in coal use per worker.* Given that substantial efficiency improvements in coal use per worker occurred over this period, this estimate would be substantially misleading.

Given this issue, I adopt the following strategy. First, I estimate Eq. 5 while ignoring the ϕ_t terms and obtain estimates of α_2. Second, I use additional data on national coal use in industry to estimate $[\ln(\phi_{t-\tau}) - \ln(\phi_{t-\tau-\delta})]$. Finally, I put these two elements together to estimate the impact of increasing coal use on mortality over the 1851-1900 period while adjusting for efficiency improvements in coal use per worker over this period.

Estimated results for Eq. 5 are presented in Table 10. I consider three potential lags for the effect of pollution to translate into mortality $\tau = \{0, 10, 20\}$ and in each specification I use the maximum possible δ.[41] Columns 1-2 display results where $\tau = 0$ and the long-difference is taken over the full four decades between 1851 and 1891. In Columns 3-4, the explanatory variables are lagged one decade behind the dependent variable and the long-difference is taken over thirty years, from 1861-1891. In Columns 5-6, the explanatory variables are lagged two decades and the long-difference is over twenty years. For each pair, I present results including either the change in actual district population or the change in predicted district employment as control variables. In all cases, I find that coal use has a strong positive effect on mortality. My preferred estimates are Columns 1-2, which allow the maximum difference.

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[41] I.e., when $\tau = 0$, $\delta = 40$, when $\tau = 10$, $\delta = 30$, and when $\tau = 20$, $\delta = 20$.

Table 10: Long-difference regression results

Length of τ:	Zero		One decade		Two decades	
Base, final year:	1851, 1891		1861, 1891		1871, 1891	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\ln(POP_{dt-\tau})$	1.009***		0.234		0.351	
	(0.318)		(0.243)		(0.366)	
$\Delta\ln(PREDpop_{dt-\tau})$		0.350		-1.510		2.549
		(3.322)		(2.213)		(2.821)
$\Delta\ln(EstCOAL_{dt-\tau})$	9.828***	10.36**	7.576**	9.263***	11.17***	9.388**
	(3.465)	(5.217)	(3.110)	(3.457)	(3.315)	(3.790)
Constant	-10.64***	-10.93***	-7.632***	-7.700***	-6.850***	-7.000***
	(2.153)	(2.362)	(1.443)	(1.465)	(1.174)	(1.156)
Observations	383	383	383	383	383	383
R-squared	0.129	0.069	0.043	0.041	0.082	0.080

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. When collapsing districts for consistency I use the mean latitude and longitude across original districts as the location for the new district. The variable $PREDpop_{dt-\tau}$ is the predicted working population of the district, calculated by taking the initial industry employment in a district, multiplying by the national growth rate in that industry, and then summing across all industries in the district.

Next, I need an estimate of the term $[\ln(\phi_{t-\tau}) - \ln(\phi_{t-\tau-\delta})]$. Using Eq. 1, this can be written as,

$$\begin{aligned} \ln(\phi_{t-\tau}) - \ln(\phi_{t-\tau-\delta}) &= [\ln(COAL_{t-\tau}) - \ln(COAL_{t-\tau-\delta})] \\ &- [\ln(EstCOAL_{t-\tau}) - \ln(EstCOAL_{t-\tau-\delta})] \end{aligned}$$

where $COAL_t$ is actual national coal use in industry and $EstCOAL_t$ is national coal use estimated by combining a fixed level of coal use per worker θ_i and national industry employment in year t. For actual national coal use data, I use values from Mitchell (1984).[42] The values of $EstCOAL_t$ are obtained by multiplying national

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[42] Specifically, I use the sum of coal use in general manufacturing, iron & steel, and mining, reported for the U.K. (p. 12), less the values in these categories reported for the main Scottish mining district (p. 17). These values are reported for 1840, 1855, 1869, 1887, and 1903. I interpolate these to obtain values for 1851 and 1891.

industry occupation in a year by the coal-per-worker values from the 1907 Census of Production. This procedure suggests that the efficiency term is equal to 0.4488 from 1851 to 1891. This reflects the substantial gains made in reducing coal use per worker in industry over this period.

In Table 11, I combine these elements in order to obtain an estimate of the impact of increasing coal use on mortality over the 1851-1900 period. The values in the first row reflect the increase in mortality, in deaths per 1,000 residents, we could have expected from pollution in the absence of any gains in coal use per worker over the 1851-1900 period. The second row shows the adjustment due to the decrease in coal use per worker across all industries during this period. The third row contains estimates of the actual increase in mortality due to the effect of pollution from 1851-1900. These results suggest that increasing industrial pollution was associated with 1.49-1.57 additional deaths per thousand from 1851-1900.

In Row 4 of Table 11, I consider values that are and are not adjusted for selection effects. To adjust for selection effects I attributed 44% of the estimated relationship between industrial pollution and mortality to the direct effects of pollution, based on the results from the previous section.[43]

The average actual change in mortality over this period, shown in Row 5, is a decrease of 4.4 deaths per thousand, which was due primarily to the reductions in infectious disease mortality. Row 6 of Table 11 suggests the reduction that would have been achieved had there been no increase in mortality due to rising levels of pollution. Finally, Row 7 provides estimates of the share of mortality gains that could have been achieved over the 1851-1900 period, but were lost due to increased pollution. These figures suggest that, of the potential mortality gains over this period, increasing pollution offset roughly 26% (without the selection adjustment) or about 13% (when making the selection adjustment).

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[43] The cause-of-death results suggested that as much as 52-60% of the relationship between pollution and mortality could be due to selection effects. Taking this midpoint of these estimates, this means that 44% is explained by the direct impact of pollution on mortality. Note that it is not possible to use the cause-of-death results to directly estimate the impact of selection on the long-difference results, as was done for the cross-sectional results in Section 4.3. This is because there is substantial variation in the correct lag lengths to use across different causes of death, so applying a single lag length across different causes is likely to generate misleading results.

Table 11: Estimated impact of increased pollution on mortality, 1851-1900

	All values in mortality per 1000 residents				
		Using estimate from Column 1 of Table 10		Using estimate from Column 2 of Table 10	
(1)	Estimated effect of increased coal use without efficiency gains $(0.6 * \alpha_2)$	5.90		6.22	
(2)	Adjustment for increased efficiency in coal use $(0.4488 * \alpha_2)$	-4.41		-4.65	
(3)	Adjusted effect of increased coal use	1.49		1.57	
		Without	With	Without	With
(4)	Effect without/with selection adjustment	1.49	0.65	1.57	0.69
(5)	Actual mortality change, 1851-1900	-4.4	-4.4	-4.4	-4.4
(6)	Expected change without pollution increase	-5.89	-5.05	-5.97	-5.09
(7)	Share of gains lost due to increased pollution	0.252	0.129	0.263	0.135

The values in the first row are calculated by multiplying the average increase in log coal use across districts from 1851 to 1891 (0.6), by the coefficient on $\Delta \ln(EstCOAL_{dt-\tau})$ from Table 10. The values in the second row are calculated by multiplying the national change in coal per worker (0.4488) by the coefficient on $\Delta \ln(EstCOAL_{dt-\tau})$ from Table 10. Row 3 is the difference between rows one and two. Row 4 adjusts the estimated mortality effects by .44, based on the share of the industrial pollution-mortality relationship that was attributed to the direct effects of pollution in Section 4.3. Row 5 is the actual average decrease in mortality across all districts from 1851-1860 to 1891-1900. Row six is row four minus row three. Row seven is one minus the absolute value of the ratio of row four to row six.

4.5 Pollution spillovers

In this section, I take advantage of wind patterns in order to look at how pollution effects spillover geographically. Understanding these pollution spillovers is useful because they have implications for the structure of British cities and their political economy. These results can also provide further evidence that the pollution effects I measure are not driven by omitted variables.[44]

In England, the predominant wind direction across all of the country is in a range

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[44] This point is made by Bayer *et al.* (2009), who exploit wind patterns to obtain variation in pollution in downwind communities that is plausibly unrelated to economic conditions in those locations.

from west to southwest.[45] Based on this wind pattern, for each of the main industrial centers of the country I have identified a set of districts lying just downwind (east or north) and another set of districts lying just upwind (west or south) of the district. I then compare outcomes in the upwind vs. the downwind districts. This is done for the main industrial centers of England in 1851: London, the Birmingham-Wolverhampton corridor, Manchester & Salford, Newcastle-upon-Tyne, Sheffield, the Stoke-upon-Trent area, Liverpool, Leicester, the Nottingham-Derby corridor, Coventry, Bristol, the Preston-Blackburn-Bolton corridor and Northampton.

The regression specification for some district d located either upwind or downwind of the central industrial metro area m is,

$$\begin{aligned} MORT_{dm} &= a_0 + a_1 \ln(POP_{dm}) + a_2 \ln(DENSITY_{dm}) + a_3 \ln(POLL_{dm}) \\ &+ a_4 \left(DOWN_d * METROpol_m\right) + \Psi_m + \epsilon_{dm} , \end{aligned}$$

where $DOWN_{dm}$ is an indicator variable for whether the district is a downwind district, Ψ_m is a full set of metro area effects, and the other variables are defined as before. I use three alternatives for the variable $METROpol_m$, which represents the expected effect of metro area pollution on the downwind districts. In some specifications I simply use an indicator variable for the downwind districts (i.e., $METROpol_m = 1$). It is important to note that when an indicator variable is used for $METROpol_m$, the estimation is not reliant on the direct measures of pollution I have constructed. This is an attractive feature that can help verify that the patterns I observe are not driven by how the pollution measures are constructed.

A second specification uses $METROpol_m = \ln(METROcoal_m)$ where $METROcoal_m$ is coal use summed over the districts in the central industrial metro area. The third specification I use is $METROpol_m = \ln(METROdi_m)$ where $METROdi_m$ is employment in heavily polluting industries in the central industrial metro area.

To make this comparison more concrete, Figure 4 describes how the central industrial metro area, upwind districts, and downwind districts are defined, for the industrial area around Birmingham. The red line in this figure encloses the cen-

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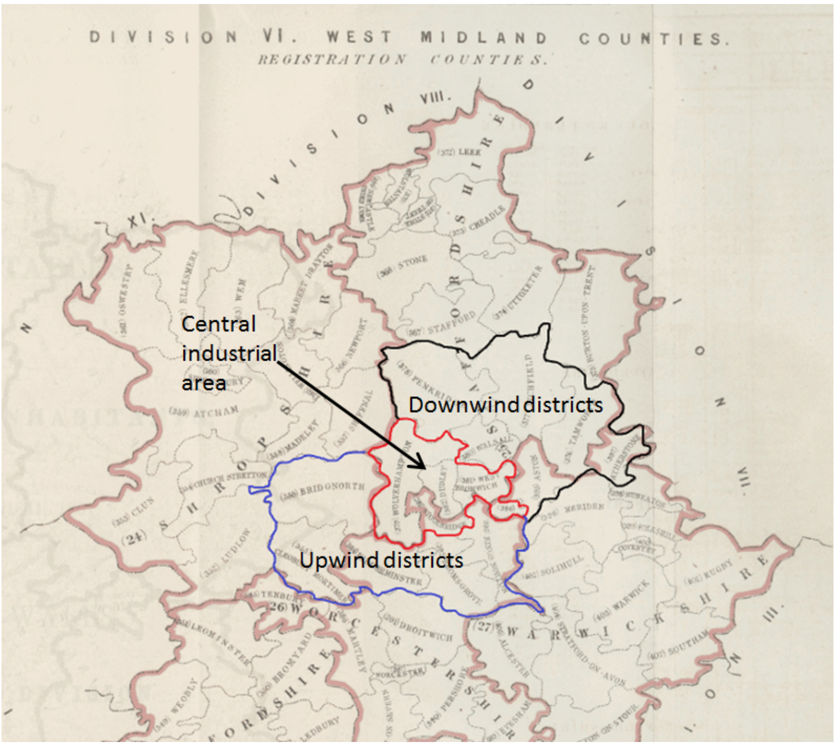
[45] See, e.g., Directorate of Weather, U.S. Army Air Force in 1942, "Climate and Weather of the British Isles" (Vol. VI, No. 2). Data available in Appendix A.3.6.

tral industrial metro area, which includes a corridor stretching from Birmingham to Wolverhampton. I have tried to define the central industrial areas in each metro to include those containing much of the heavy industry. The districts in the central industrial metro area are used to calculate the coal use and polluting industry employment values, $METROcoal_m$ and $METROdi_m$. The blue line indicates the upwind districts, which can be thought of as the control group for this metro area. The black line encloses the downwind districts, which can be thought of as a treatment group, where the treatment is receiving pollution generated in the central industrial area.

Figure 4: Upwind and downwind districts around the Birmingham industrial area



The red line encloses the central industrial area, which stretches from Birmingham district in the east to Wolverhampton in the west and includes the districts of Dudley, West Brom and Stourbridge. The black line encloses the downwind districts, while the blue line encloses the upwind districts.

Table 12 presents results obtained by comparing the upwind and downwind districts. All of these regressions include a full set of metro area effects. In all regressions I cluster the standard errors of the downwind districts and upwind districts, separately, for each metro area. This is done to allow spatial correlation across these neighboring districts.

Columns 1-3 present results without any district-level controls. All of these results suggest that mortality was higher in districts downwind of the major industrial centers of the country. The result in Column 1 is particularly valuable because it does not rely on either of my direct pollution measures. These estimates can be thought of as the *total effect* of being downwind from a major pollution center, which includes both the *direct impact* of spillover pollution on mortality as well as the indirect impact occurring through changes in other district features that take place in response to being downwind and also affect health. As an example of these indirect effects, I find evidence of increased coal use, dirty industry employment, and population in downwind districts relative to upwind districts in the same metro area.[46] Regardless of whether the mortality results are driven by direct or indirect effects, these results provide causal evidence that pollution is having an important impact on the urban system. Identification of these causal effects requires only the assumption that there are no other factors that systematically affect downwind districts differently than upwind districts.

In Columns 4-5, I add in controls for district population, population density, and one of my measures of district pollution levels. Here I continue to find evidence that mortality is higher in downwind districts. These estimates can be thought of as getting closer to the *direct effect* of being downwind from a pollution center, though they may still contain some indirect factors. The magnitude of the estimated impact of being downwind from a major industrial center drops by around half compared to the estimates in Columns 2-3, signaling that these additional controls are capturing some of the indirect effects of pollution. I continue to find that population density and district pollution increase mortality. In Columns 6-7, I add in the remaining district-level controls. Including these has very little impact on the results.

In terms of magnitude, my preferred results, in Column 7, suggest that a one standard deviation increase in coal use in the central industrial district (5.61) increases the mortality rate in downwind districts by 0.45 per thousand. A one standard

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[46] There is also evidence that downwind districts are more densely populated, but this relationship is not statistically significant. These factors indicate that downwind districts likely attracted poorer residents which lived more densely. The fact that I find more polluting industries in downwind districts is likely due to the economic pull of lower land rents in less attractive areas, though political pressure by wealthier residents to keep polluting industries out of upwind districts may have also played a role.

deviation increase in employment in dirty industries in the central industrial area is consistent with an increase in mortality in downwind districts of 0.56 per thousand. Thus, as expected, the impact of pollution on downwind communities is substantially smaller than the impact of locally produced pollution.

Table 12: Regressions comparing downwind to upwind districts

	DV: Age-standardized mortality						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Downwind indicator	1.394*** (0.440)						
Downwind × Ln($METROcoal_m$)		0.149*** (0.0382)			0.0840*** (0.0214)		0.0804*** (0.0235)
Downwind × Ln($METROdi_m$)			0.236*** (0.0509)	0.109*** (0.0347)		0.100** (0.0379)	
Ln(Coal use)					1.900*** (0.464)		2.069*** (0.589)
Ln(Dirty emp.)				1.137*** (0.281)		1.230*** (0.337)	
Ln(District pop.)				-0.620 (0.632)	-1.473 (0.890)	-0.560 (0.571)	-1.501* (0.829)
Ln(Pop. Density)				1.338*** (0.253)	1.231*** (0.205)	1.239*** (0.256)	1.092*** (0.217)
Metro effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other controls						Yes	Yes
Observations	77	77	77	77	77	77	77
R-squared	0.528	0.550	0.567	0.802	0.810	0.804	0.812

*** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the metro area level for upwind districts and downwind districts separately. All regressions include a full set of metro area effects. Columns 6 and 7 include the following additional controls: employment in water services per 10,000 population in 1851, employment in medical services per 10,000 population in 1851, a seaport indicator variable, and seaport tonnage in 1865.

I have explored the sensitivity of these results to excluding particular metro areas from the analysis.[47] Dropping any one metro area does not substantially effect either the coefficient or the statistical significance of the total effects results presented in Columns 1-3. The results focused on the direct effect, in Columns 4-7, are sensitive to dropping the larger metro areas, particularly London and Birmingham, which pro-

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[47] These results are available in Appendix A.3.7.

duced the most pollution and therefore generated the strongest effects on downwind districts.

In summary, the results in Table 12 show that areas located downwind from England's major industrial centers experienced greater mortality than districts upwind of the same center. In the absence of airborne pollution, it is difficult to come up with an alternative explanation for why I observe such a consistent pattern across the industrial centers of England. Thus, I interpret these results as offering strong evidence in favor of the impact of industrial pollution on downwind districts. My results suggest that this impact was due to a combination of direct and indirect effects. Indirect effects most likely operated through the selection of local residents, which in turn influenced local land prices and the composition of local industries.

5 Conclusions

This paper provides evidence that industrial pollution was a major contributor to mortality in 19th century Britain. In the cross-section in 1851-1860, the effects of pollution are at least one-third as large as all other impact of population density, and may be as large as 80% of the density effect. Moreover, rising pollution levels due to the growth of industry and increased coal burning had a substantial impact on mortality over the 1851-1900 period. These effects have largely been missed because they occurred during a period in which a spectacular decrease in infectious diseases led to an overall decline in the mortality rate. However, I find that the mortality declines during this period would have been even more rapid – by between 13 and 26 percent – were they not partially offset by rising mortality associated with industrial pollution.

There are a number of reasons to believe that the results presented in this paper understate the true effect of pollution on mortality during the 19th century. For example, migration between districts will bias my results downward. Similarly, my results reflect only the impact of industrial pollution; it is likely that other pollution sources, particularly residential pollution, had additional mortality effects. In addition, my results do not reflect potential avoidance behaviors that may have worked to reduce the pollution impacts that I estimate. Thus, we should expect the estimated impact of pollution on mortality during this period to increase as additional work dealing with these issues becomes available.

Due in part to lack of evidence, much of the recent work dealing with health and mortality during this period has largely ignored the role of pollution. Cutler *et al.* (2006), for example, discuss the health effects of urbanization in Britain, but never directly discuss industrial pollution. In Deaton (2013), pollution merits only a passing remark (p. 94). Focusing on the U.S., Costa (2013) describes Pittsburgh skies darkened by pollution, but she argues that the lack of reliable particulate data limit our ability to measure the impact of pollution, or assess the benefits generated as air quality improved. This study fills this gap in the literature by providing broad-based and well-identified evidence of the impact of industrial pollution on mortality in the 19th century.

One additional reason to care about the results presented here is that they can influence how we think about economic growth patterns in the 19th and 20th centuries. Nordhause & Tobin (1973) point out that when economic growth is accompanied by negative environmental externalities such as pollution, standard measures of GDP may fail to capture the true evolution of welfare gains. The extremely high levels of pollution during the 19th century suggest that measures of welfare or “green GDP” may differ substantially from standard GDP measures during that period. This would lead GDP to overstate the gains from economic progress in the 19th century, as well as underestimating the welfare gains associated with improving the environment in the 20th century.

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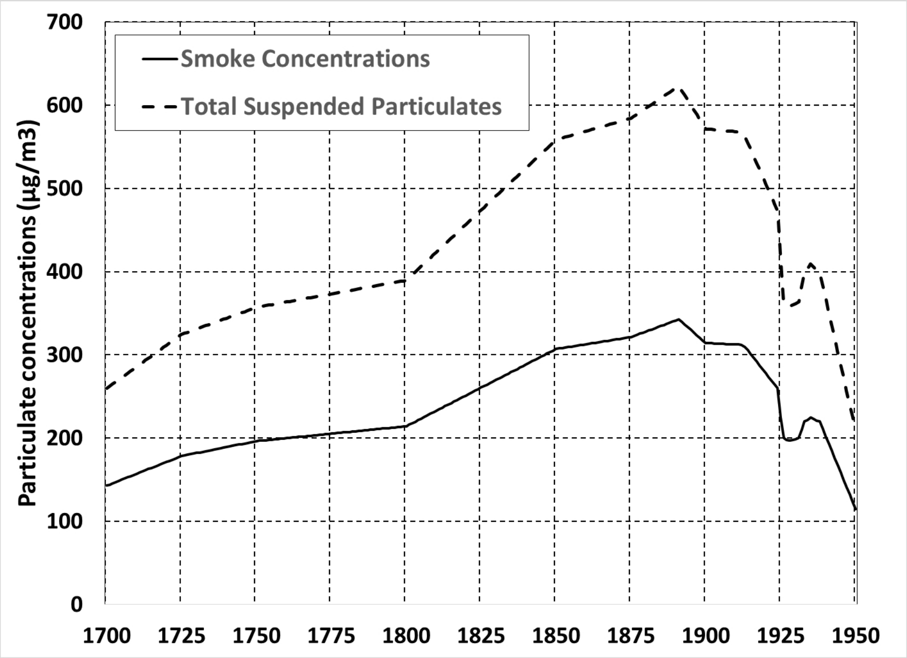
A Appendix

A.1 Empirical setting appendix

A.1.1 Estimated pollution levels in London from 1700

While broad direct measures of pollution are not available for the historical period, Brimblecombe (1987) has produced estimates of smoke concentrations for London starting in 1700.[48] These have been converted to total suspended particulate (TSP) values, a standard pollution measure, by Fouquet (2008). Figure 5 plots these values. These show that the period covered by this study covers the highest pollution decades for London.

Figure 5: Estimates of historical smoke concentrations and TSP levels for London



Smoke concentration estimates from Brimblecombe (1987) converted to TSP levels by Fouquet (2008).

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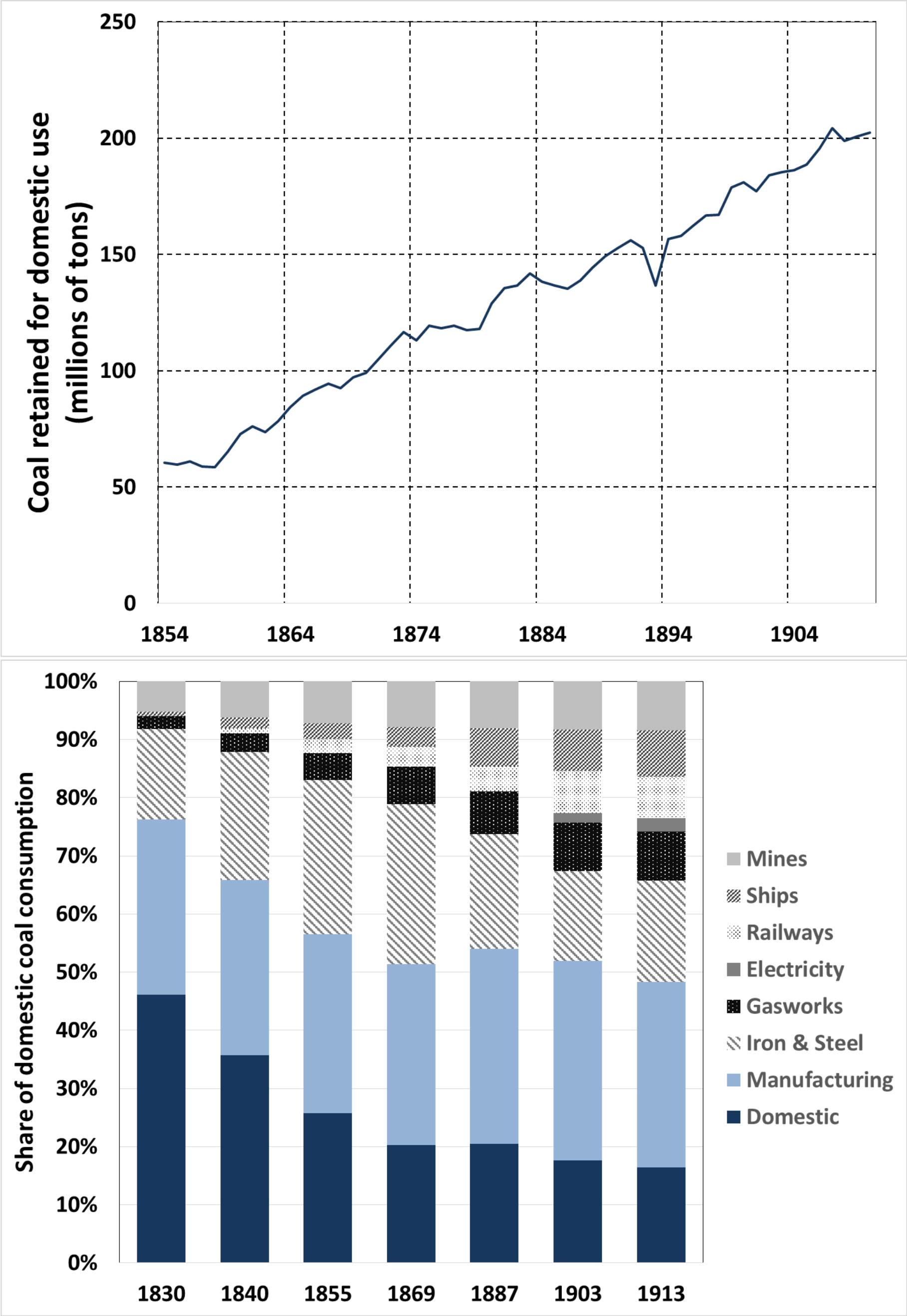
[48] Brimblecombe's measures are constructed using data on imports of coal into London.

A.1.2 National coal use patterns

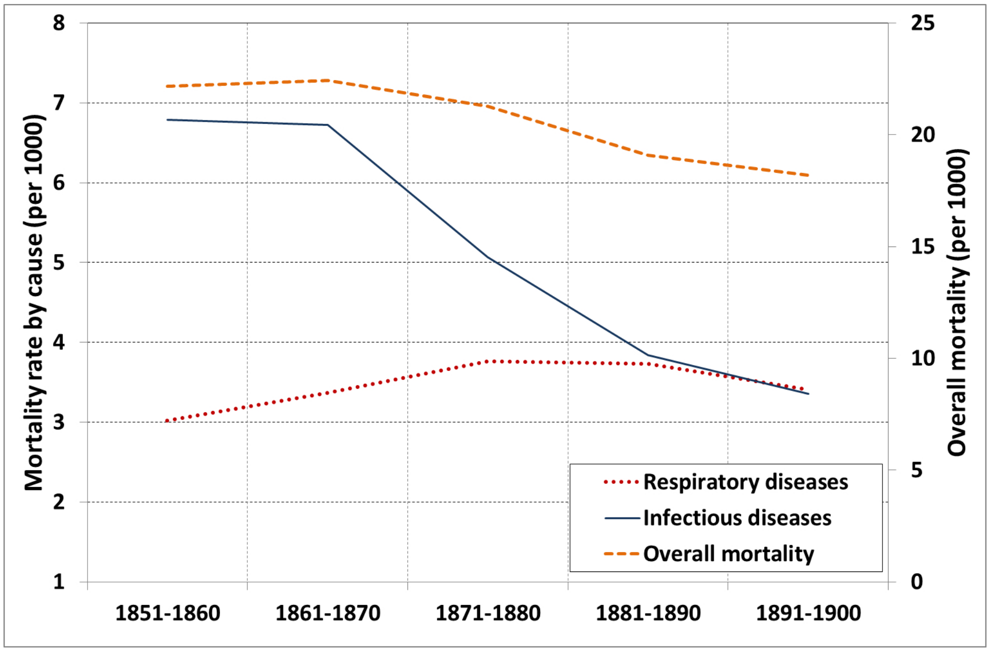
Figure 6: Domestic consumption of coal and coal usage shares for the U.K.



Data from Mitchell (1988).

A.1.3 National mortality trends

Figure 7: National mortality patterns, 1851-1890



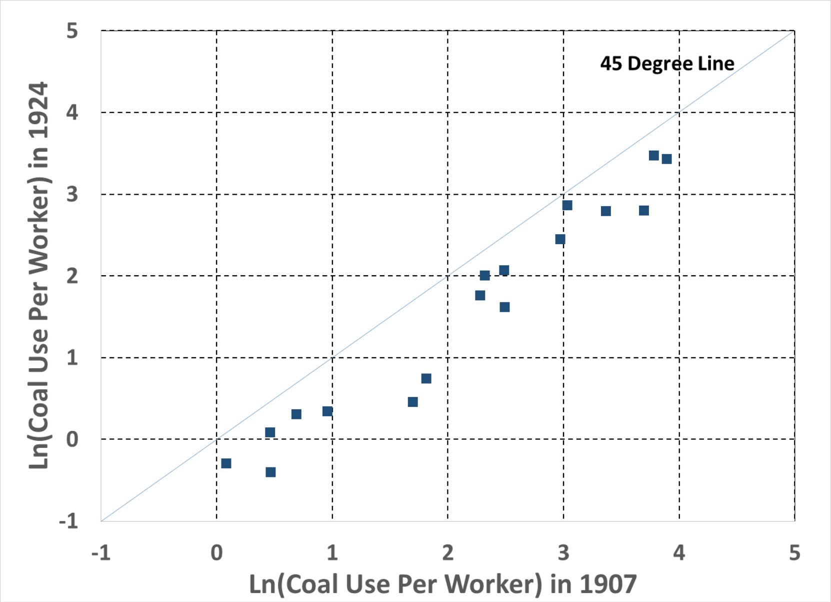
The infectious diseases included are cholera, diarrhea & dysentery, diphtheria, measles, scarlet fever, smallpox, tuberculosis, typhus and whooping cough.

A.2 Data appendix

A.2.1 Assessing the stability of relative industry coal use

This appendix provides an analysis of the stability of relative coal use intensity across industries. This is done by comparing industry coal use intensity in 1907 to values from the next Census of Production, which was taken in 1924. Using these two Census observations, Figure 8 looks at how much the relative coal intensity of industries changed over time. We can see that coal use per worker has shifted down for all industries, but that the slope is indistinguishable from zero, suggesting that there has been no clear change in relative industry coal use intensity over this period. I.e., while efficiency gains were made in overall coal use, the relative coal intensity of industries was remarkably stable over time.

Figure 8: Comparing industry coal use in 1907 and 1924



	DV: Coal per worker in 1924
Coal per worker in 1907	1.021***
	(0.0612)
Constant	-0.623***
	(0.151)
Observations	17
R-squared	0.949

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A.2.2 Summary statistics for robustness checks

Table 13 describes summary statistics for the regressors used in Table 6.

Table 13: Summary statistics for alternative explanatory variables

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Dirty ind. emp. share	527	0.16	0.16	0.02	0.69
Coal per worker (tons)	527	4.88	3.85	1.09	26.41
Ln(Coal per acre)	527	-0.47	1.55	-3.53	5.88
Ln(Dirty ind. emp. per acre)	527	-4.03	1.71	-7.12	2.15
Ln(Clean ind. emp.)	527	8.64	0.60	6.62	11.37

Table 14: Relative industry wage levels over time

Industry	1850	1860	1870	1880	1891
Cotton	52	62	72	82	97
Wool	69	76	84	96	87
Construction	122	138	160	173	177
Mining	108	124	132	128	183
Iron	142	150	170	176	187
Sailors	100	119	123	120	168
Agriculture	71	87	92	104	100

Wages are indexed with agriculture in England in 1891 = 100.

A.2.3 Industry wage data

Table 14 contains data from Bowley (1900), *Wages in the United Kingdom in the Nineteenth Century* (p. 132), describing relative industry wage levels over time. We can see that the most polluting industries on this list, iron and mining, paid relatively high wages compared to less polluting industries.

A.3 Analysis appendix

A.3.1 Weighted regression results

Table 15 presents regression results where each district is weighted by average district population.

Table 15: Weighted cross-sectional regressions for 1851-1860

	DV: Age-standardized mortality					
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Pop. Density)	2.084***				1.537***	1.575***
	(0.101)				(0.111)	(0.119)
Ln(District pop.)		3.570***			-0.868**	-0.276
		(0.248)			(0.352)	(0.254)
Ln(Coal use)			2.549***		1.500***	
			(0.207)		(0.307)	
Ln(Dirty emp.)				2.199***		0.981***
				(0.192)		(0.201)
Region controls	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	527	527	527	527	527	527
R-squared	0.867	0.765	0.813	0.803	0.887	0.886

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, are clustered at the county level to allow some spatial correlation. These are used in place of spatially correlated standard errors, which are more difficult to calculate in weighted regressions. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. Analytical weights are based on average district population over the decade. Other control variables include employment in water services per 10,000 population in 1851, employment in medical services per 10,000 population in 1851, a seaport indicator variable, and seaport tonnage in 1865.

A.3.2 Age results

This appendix explores the impact of pollution on mortality at particular age categories using cross-sectional results mirroring those used in the baseline analysis. I consider two regression specifications,

$$MORT_d^{AGE} = \beta_0 + \beta_1 \ln(POP_d) + \beta_2 \ln(DENSITY_d) + \beta_3 \ln(COAL_d) + X_d\Lambda + R_d + \epsilon_d \,,$$

$$\ln\left(MORT_d^{AGE}\right) = \beta_0 + \beta_1 \ln(POP_d) + \beta_2 \ln(DENSITY_d) + \beta_3 \ln(COAL_d) + X_d\Lambda + R_d + \epsilon_d \,,$$

where the AGE superscript indicates mortality in a particular age group.[49] The regressions include the full set of controls. Standard errors are clustered by county to allow some spatial correlation.

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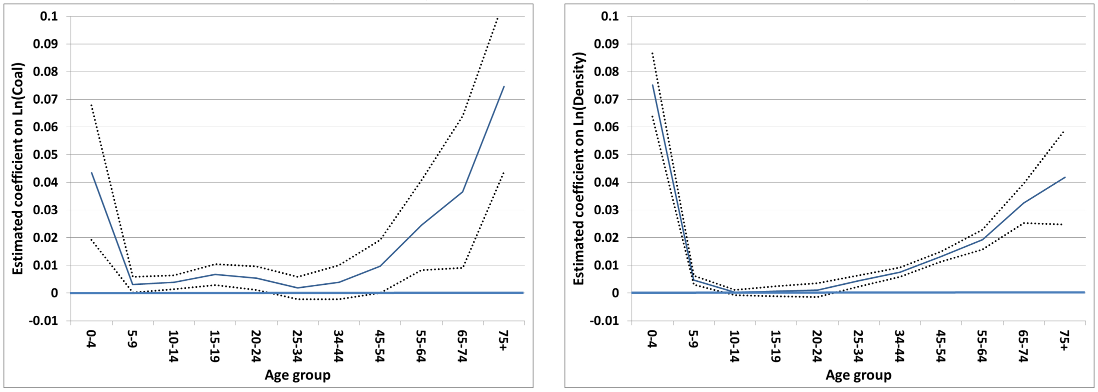
[49] Note that age-specific mortality data are not age-standardized.

Figure 9 presents the estimated coefficient for each age group for the pollution measure (Ln(COAL)) and district density. The top panel looks at the impact on the mortality rate per thousand while the bottom panel looks at the impact on the log mortality rate in order to assess the percentage increase in mortality. These estimates suggest that pollution affected both the young and the old. There is also evidence of higher mortality among young adults, age 15-19, in more polluted areas. The pollution effects are similar to the effects of density, though the pollution effects appear stronger for adults and the elderly, while density effects, which are associated with infectious diseases, have a relatively greater impact on young children. The results in the bottom panel suggest that, in percentage terms, pollution had a similar impact across age categories, while density shows a clear pattern of large effects among the young and old and no effect on ages 10-25.

Figure 9: Impact of pollution and population density on mortality by age group

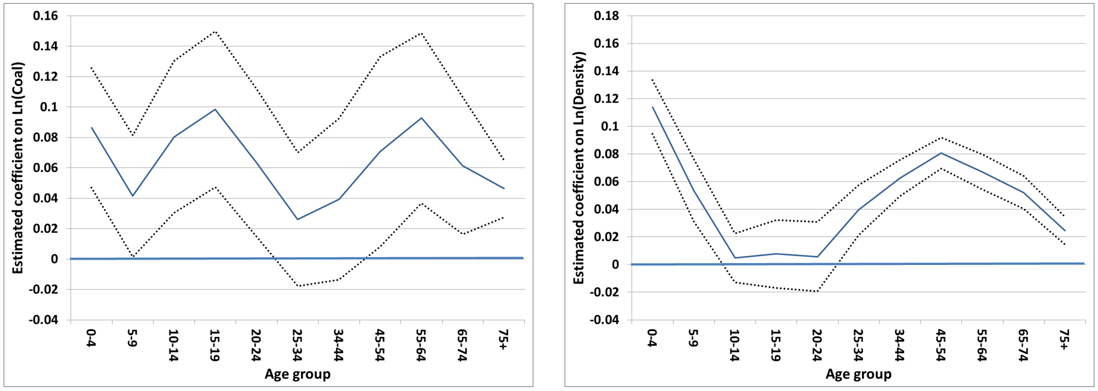
DV: Age-standardized mortality

Coefficient on ln(COAL) Coefficient on ln(DENSITY)



DV: Ln(Age-standardized mortality)

Coefficient on ln(COAL) Coefficient on ln(DENSITY)



Regressions are run on a cross-section of data from 1851-1860. There are 524 observations. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. All regressions include the log of district population, district population density and coal use, as well as district medical employment per 10,000 residents, water services employment per 10,000 residents, an indicator variable for whether the district is a seaport, and the import tonnage coming in through the port.

To make more sense of these patterns, I look at how the impact of pollution varies across ages and causes of death. Table 16 presents these results for a set of age and cause-of-death categories. For the young, pollution primarily affects the respiratory and neurological systems. The neurological effects may result from en utero exposure,

Table 16: Pollution coefficients for cause-of-death by age category regressions

	Children under 5	Children 5 - 15	Young 15 - 25	Adults 25 - 55	Elderly over 55
Respiratory diseases	0.00933**	0.000208	5.29e-05	0.00162*	0.00981
	(0.00469)	(0.000193)	(0.000259)	(0.000908)	(0.00624)
Circulatory diseases	0.000333	0.000146	0.000178	7.73e-05	0.00300
	(0.000255)	(0.000149)	(0.000204)	(0.000377)	(0.00338)
Neurological diseases	0.0129**	0.000352*	2.96e-05	-0.000273	0.00112
	(0.00543)	(0.000197)	(0.000196)	(0.000487)	(0.00201)
Digestive diseases	0.00124	1.52e-05	0.000431**	0.000648**	0.00169
	(0.00119)	(0.000101)	(0.000214)	(0.000299)	(0.00112)
Infectious diseases	0.00488	0.00109	0.00196	0.000678	0.00508**
	(0.00391)	(0.000891)	(0.00178)	(0.00128)	(0.00220)
Other non-infectious	0.00995	-0.000161	0.000216	-0.00104*	-0.00539
	(0.00704)	(0.000285)	(0.000347)	(0.000602)	(0.00673)

*** p<0.01, ** p<0.05, * p<0.1. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. All regressions include (not reported) the log of district population, the log of district population density, a full set of region effects, and control variables for employment in water services per 10,000 population in 1851, employment in medical services per 10,000 population in 1851, a seaport indicator variable, and seaport tonnage in 1865.

or they may be due to exposure to lead that was released by polluting industries. At older ages, pollution affects the respiratory system and the digestive system, and these effects appear to grow over time. Pollution increases mortality related to infectious diseases across many age groups, though this effect is often not statistically significant.

A.3.3 Cause-of-death results with alternative pollution measure

Table 17 presents cause-of-death results using the pollution measure based on employment in dirty industries. The results in Table 17 suggest that a one s.d. increase in the log of local dirty industry employment (1.28) is associated with an increase mortality in the NPR categories of 1.15-1.52%. The impact on total mortality is estimated to be 5.43%. This suggests that, after adjusting for selection, a one s.d. increase in the log of dirty industry employment increases mortality by 3.91-4.28% (0.77-0.84 deaths per thousand), a figure that is somewhat larger than the increase found using the measure of pollution based on local coal use. In these results, selection accounts for 21-28% of the relationship between pollution and mortality.

Table 17: Cause-of-death results with dirty industry measure

	DV: Ln(Age-standardized mortality)				
Category:	NPR1	NPR2	Total mortality	Pollution related	Respiratory only
	(1)	(2)	(3)	(4)	(5)
Ln(Dirty emp.)	0.0119	0.00896	0.0424***	0.0552***	0.0682***
	(0.0176)	(0.0158)	(0.00762)	(0.0137)	(0.0260)
Ln(Pop. Density)	0.138***	0.136***	0.0749***	0.0780***	0.143***
	(0.0144)	(0.0122)	(0.00453)	(0.00560)	(0.0139)
Ln(District pop.)	0.0934**	0.0812**	-0.0205*	-0.0411**	-0.0137
	(0.0402)	(0.0325)	(0.0119)	(0.0186)	(0.0368)
Water service emp.	0.000575	0.00118	-0.00198	-5.39e-05	0.00592
	(0.00601)	(0.00535)	(0.00285)	(0.00243)	(0.00360)
Medical service emp.	-0.000535	-0.000364	-0.000338	0.000118	-0.000609
	(0.000769)	(0.000693)	(0.000248)	(0.000319)	(0.000801)
Seaport tonnage	-0.0106	-0.0130	0.0494***	0.0503***	0.0857**
	(0.0423)	(0.0383)	(0.0101)	(0.0144)	(0.0338)
Seaport indicator	0.0383	0.0417	-0.00226	-0.0234	-0.0527*
	(0.0443)	(0.0404)	(0.0130)	(0.0163)	(0.0292)
Constant	0.0230	0.263	2.975***	2.355***	0.636*
	(0.403)	(0.328)	(0.117)	(0.162)	(0.334)
Region controls	Yes	Yes	Yes	Yes	Yes
Observations	522	522	522	522	522
R-squared	0.545	0.565	0.736	0.653	0.574

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. The NPR1 causes in Column 1 contains five infectious diseases that do not primarily affect the respiratory system: Cholera (which includes diarrhea), Diphtheria, Scarlet Fever, Smallpox, and Typhus. The NPR2 causes in Column 2 contains the NPR1 categories plus mortality related to kidneys, the urinary system, and the generative organs. Column 3 presents results for overall mortality. Column 4 presents results for mortality from a set of cause-of-death commonly associated with pollution: respiratory diseases, cardiovascular and circulatory diseases, cancer, digestive diseases, diseases of the nervous system, death in childbirth, and two infectious diseases of the respiratory system, measles and tuberculosis. Column 5 looks only at respiratory system mortality, the category most closely associated with the effects of air pollution.

Table 18 describes the relationship between the pollution measure based on dirty industry employment and violent death. After subtracting this effect (adjusted for selection), the remaining impact of dirty industry employment on local mortality is equal to 0.69-0.76 deaths per thousand, or 3.5-3.9% of overall mortality.

Table 18: Estimated relationship between pollution and violent deaths using dirty ind. emp.

	DV: Age-standardized mortality (1)	**DV: Ln(Age-standardized mortality)** (2)
Ln(Dirty emp.)	0.0173	0.0255
	(0.0155)	(0.0248)
Ln(Pop. Density)	0.0410**	0.0476**
	(0.0167)	(0.0233)
Ln(District pop.)	0.00803	0.0248
	(0.0295)	(0.0419)
Region effects	Yes	Yes
Control vars.	Yes	Yes
Observations	527	527
R-squared	0.317	0.315

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. These additional control variables included are log district population, water service employment, medical service employment, a seaport indicator variable and seaport tonnage.

A.3.4 Selection adjustment for child mortality only

When applying the selection adjustment described in Section 4.3, we may be concerned that the impact of the NPR cause-of-death categories may be distributed across age groups in a different way than total mortality or mortality due to pollution-related causes of death. In fact, the NPR categories are skewed slightly more toward child mortality than total mortality or the pollution related categories. If selection operates differentially at different ages, then this may be a cause for concern when applying the selection adjustment to all-age mortality.

One way to check whether this is a potential issue is to apply a similar selection adjustment to mortality within a specific age category. A natural choice here is children, where high levels of mortality spread across many cause-of-death categories provide the necessary variation to estimate selection effects when focusing on a specific age category. An added advantage of focusing on child mortality is that much of the existing literature has focused on infant and child mortality, so this analysis provides an additional point of comparison.

Table 19 provides results for child mortality mirroring the all-age mortality results shown in Table 8. The results in Columns 1-2 suggest that there are may be some selection effects operating in this age category, though these effects are not statistically significant. The coefficient estimates suggest that a one s.d. increase in coal use is associated with an increase in child mortality of 1.0-1.2%. The estimated impact of pollution across all cause-of-death categories from Column 3 suggests that a one s.d. increase in pollution raised child mortality by 6.9%. After adjusting for selection, this suggests that a one s.d. increase in pollution raised overall child mortality by 5.7-5.9%.[50] As before, we can also see that the estimated effect is even larger in categories more closely associated with the impact of air pollution, in Columns 5-6. Overall, these results show that the percentage increase in child mortality due to pollution was similar, but slightly larger, than the percentage increase in all-age mortality estimated in the main text.

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[50] I do not need to subtract out the effect of violence here since the relationship between pollution and child mortality due to violence was negligible.

Table 19: Analyzing selection effects using cause-of-death for children

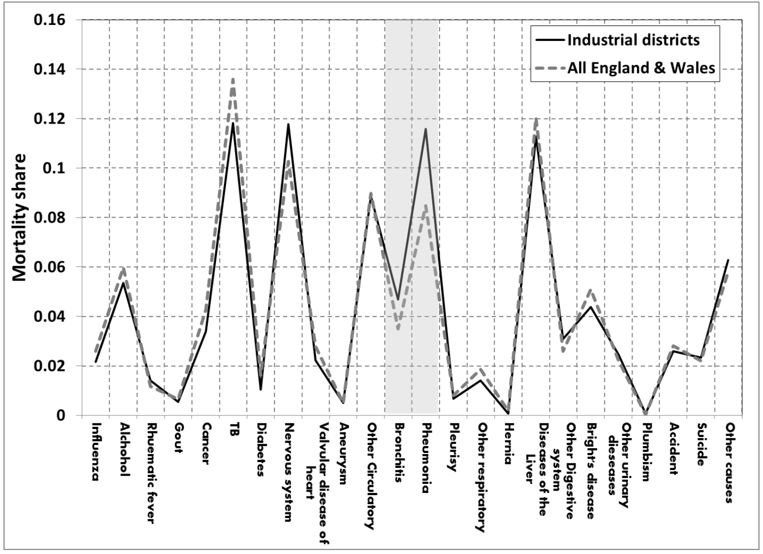
	DV: Ln(Age-standardized mortality)				
Category:	NPR1	NPR2	Total mortality	Pollution related	Respiratory only
	(1)	(2)	(3)	(4)	(5)
Ln(Coal use)	0.00927	0.0110	0.0631***	0.119***	0.0836
	(0.0433)	(0.0430)	(0.0202)	(0.0371)	(0.0528)
Ln(Pop. Density)	0.208***	0.207***	0.118***	0.123***	0.162***
	(0.0212)	(0.0212)	(0.00933)	(0.0134)	(0.0164)
Ln(District pop.)	0.178**	0.176**	0.00929	-0.0446	0.00931
	(0.0823)	(0.0819)	(0.0271)	(0.0365)	(0.0587)
Water service emp.	0.00764	0.00763	-0.00177	0.00214	0.000864
	(0.00702)	(0.00707)	(0.00502)	(0.00628)	(0.00508)
Medical service emp.	0.000467	0.000463	-0.00131**	-0.00118*	-0.00165*
	(0.00106)	(0.00106)	(0.000518)	(0.000604)	(0.000872)
Seaport tonnage	-0.206***	-0.205***	-0.00138	0.0351	0.0672*
	(0.0521)	(0.0517)	(0.0165)	(0.0352)	(0.0395)
Seaport indicator	0.0948	0.0962	0.0259	0.0158	-0.0180
	(0.0626)	(0.0625)	(0.0183)	(0.0275)	(0.0380)
Constant	0.991**	0.994**	3.706***	2.417***	1.687***
	(0.488)	(0.490)	(0.188)	(0.297)	(0.373)
Region controls	Yes	Yes	Yes	Yes	Yes
Observations	527	527	527	527	527
R-squared	0.646	0.647	0.735	0.683	0.560

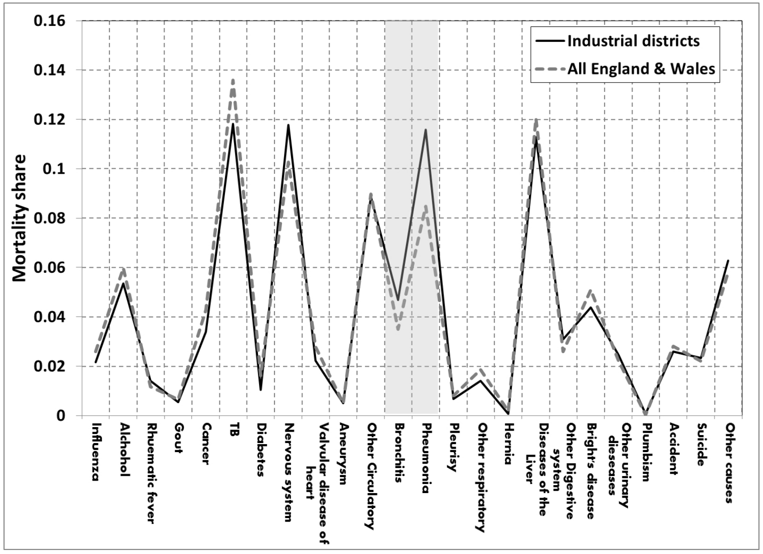
*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors, in parenthesis, allow spatial correlation between any districts within 50km of each other. Mortality data are for children 5 years and younger for the decade 1851-1860. Pollution measures are based on each district's industrial composition in 1851. The NPR1 causes in Column 1 contains five infectious diseases that do not primarily affect the respiratory system: Cholera (which includes diarrhea), Diphtheria, Scarlet Fever, Smallpox, and Typhus. The NPR2 causes in Column 2 contains the NPR1 categories plus mortality related to kidneys, the urinary system, and the generative organs. Column 3 presents results for overall mortality. Column 4 presents results for mortality from a set of cause-of-death commonly associated with pollution: respiratory diseases, cardiovascular and circulatory diseases, cancer, digestive diseases, diseases of the nervous system, death in childbirth, and two infectious diseases of the respiratory system, measles and tuberculosis. Column 5 looks only at respiratory system mortality, the category most closely associated with the effects of air pollution.

A.3.5 Cause-of-death results within occupation: further results

Figure 10 describes, separately, the share of mortality in each cause of death category for the industrial districts and England & Wales as a whole.

Figure 10: Relative importance of causes of death by type of location

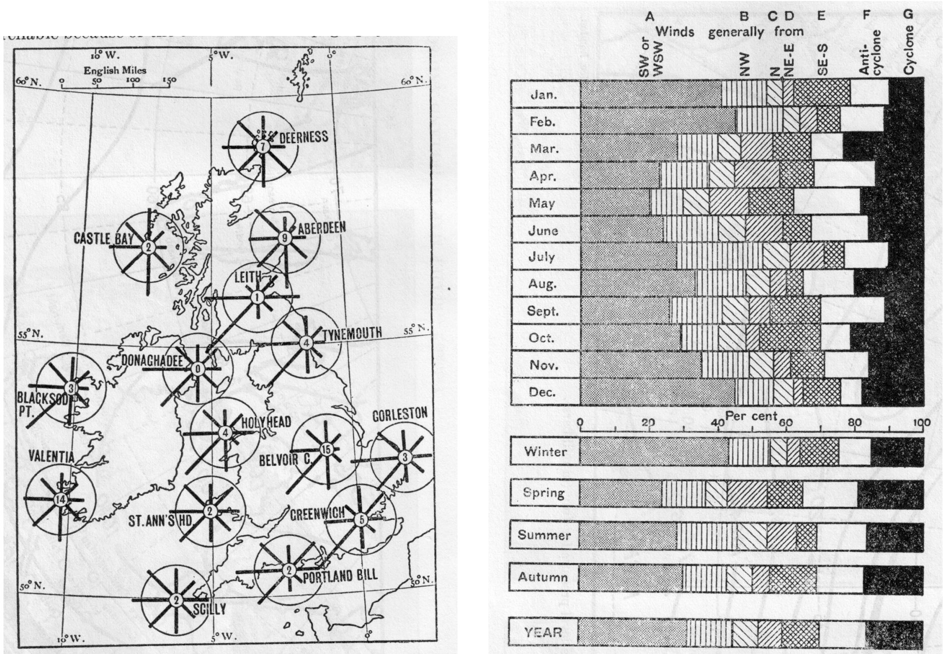

General Labourers


Innkeepers

A.3.6 Data on wind patterns

For information about wind patterns I draw on a detailed report by the Directorate of Weather, U.S. Army Air Force in 1942, "Climate and Weather of the British Isles" (Vol. VI, No. 2). The left-hand panel of Figure 11 shows graphically the wind direction at different points in the British Isles. Each point is based on a weather station. The length of the bars emanating from each point reflect the percentage of time that the wind blows from a particular direction. The right-hand panel shows the directions by month and season for the country as a whole. Across the entire country the predominant wind direction ranges from west to south, with a southwest wind most common. Importantly, this is particularly true in the winter, when the impact of pollution was particularly damaging because of the addition of smoke from residential heating to the normal industrial pollution. The pollution was so substantial at the time of this report, and the wind so consistent, that the report describes how, "The trails of smoke from industrial areas have been utilized by British pilots as a guide to location, especially over the North Sea...For example, the pilot coming down the North Sea from the north with a westerly wind near the surface, meets successively the Tyne smoke belt, the Tees belt, and the Yorkshire and Midlands belt" (p. 50).

Figure 11: Wind direction in England



(The difference between the radii of the large and small circles represents 12½ per cent. The figures in the small circles show the percentage frequencies of calms.)

Source: Bilham, *The Climate of the British Isles.*

FIGURE 5.—Average annual percentage frequencies of winds from each direction.

(Each type is represented by a shaded band, the breadth of which is proportional to the percentage frequency.)

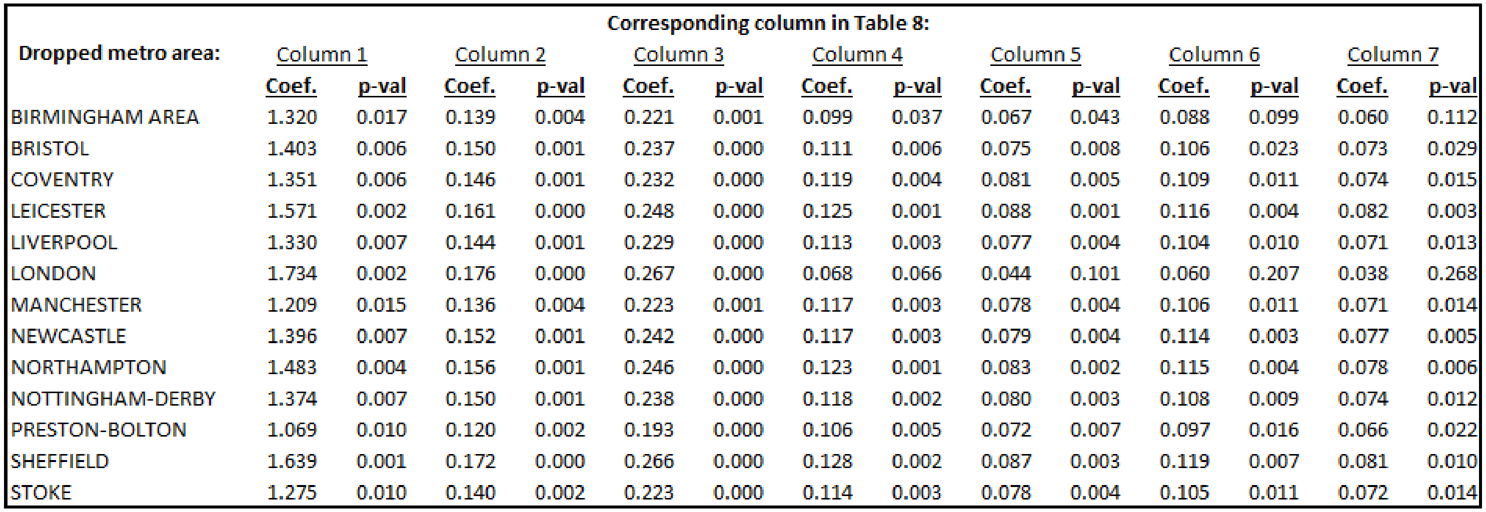
Source: Bilham, *The Climate of the British Isles.*

FIGURE 4.—Monthly and seasonal percentage frequencies of predominating weather types.

A.3.7 Robustness of downwind vs. upwind results

Table 20 explores the sensitivity of the results shown in Table 12 to dropping particular metro areas. Because the exercise involves only 13 areas, losing one of them can have a substantial effect. This is particularly true of the most polluting areas, which have larger effects on downwind districts. To explore this issue, I have calculated results dropping each of the 13 metro areas in turn, using specifications corresponding to each of the columns in Table 12. The resulting coefficients and p-values for the downwind variable in each regression is presented in Table 20. Dropping London has the most effect, followed by Birmingham. When London is dropped I still find strong evidence that downwind districts have higher mortality, but once additional controls are included this effect is generally not statistically significant.

Table 20: Robustness of downwind vs. upwind results to dropping metro areas



	Corresponding column in Table 8:													
Dropped metro area:	Column 1		Column 2		Column 3		Column 4		Column 5		Column 6		Column 7	
	Coef.	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**
BIRMINGHAM AREA	1.320	0.017	0.139	0.004	0.221	0.001	0.099	0.037	0.067	0.043	0.088	0.099	0.060	0.112
BRISTOL	1.403	0.006	0.150	0.001	0.237	0.000	0.111	0.006	0.075	0.008	0.106	0.023	0.073	0.029
COVENTRY	1.351	0.006	0.146	0.001	0.232	0.000	0.119	0.004	0.081	0.005	0.109	0.011	0.074	0.015
LEICESTER	1.571	0.002	0.161	0.000	0.248	0.000	0.125	0.001	0.088	0.001	0.116	0.004	0.082	0.003
LIVERPOOL	1.330	0.007	0.144	0.001	0.229	0.000	0.113	0.003	0.077	0.004	0.104	0.010	0.071	0.013
LONDON	1.734	0.002	0.176	0.000	0.267	0.000	0.068	0.066	0.044	0.101	0.060	0.207	0.038	0.268
MANCHESTER	1.209	0.015	0.136	0.004	0.223	0.001	0.117	0.003	0.078	0.004	0.106	0.011	0.071	0.014
NEWCASTLE	1.396	0.007	0.152	0.001	0.242	0.000	0.117	0.003	0.079	0.004	0.114	0.003	0.077	0.005
NORTHAMPTON	1.483	0.004	0.156	0.001	0.246	0.000	0.123	0.001	0.083	0.002	0.115	0.004	0.078	0.006
NOTTINGHAM-DERBY	1.374	0.007	0.150	0.001	0.238	0.000	0.118	0.002	0.080	0.003	0.108	0.009	0.074	0.012
PRESTON-BOLTON	1.069	0.010	0.120	0.002	0.193	0.000	0.106	0.005	0.072	0.007	0.097	0.016	0.066	0.022
SHEFFIELD	1.639	0.001	0.172	0.000	0.266	0.000	0.128	0.002	0.087	0.003	0.119	0.007	0.081	0.010
STOKE	1.275	0.010	0.140	0.002	0.223	0.000	0.114	0.003	0.078	0.004	0.105	0.011	0.072	0.014