Volume Title: The Economics of Climate Change: Adaptations Past and Present

Volume Author/Editor: Gary D. Libecap and Richard H. Steckel, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-47988-9
ISBN13: 978-0-226-47988-0

Volume URL: http://www.nber.org/books/libe10-1

Conference Date: May 30-31, 2009

Publication Date: May 2011

Chapter Title: Did Frederick Brodie Discover the World's First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog

Chapter Authors: Karen Clay, Werner Troesken

Chapter URL: http://www.nber.org/chapters/c11990

Chapter pages in book: (281 - 309)

10

Did Frederick Brodie Discover the World's First Environmental Kuznets Curve?
Coal Smoke and the Rise and Fall of the London Fog

Karen Clay and Werner Troesken

10.1 Introduction

In 1903, at a meeting of the Royal Meteorological Society, a British climatologist named Frederick J. Brodie presented a deceptively simple paper. Using data from the Brixton weather station in London, Brodie graphed the number foggy days per year between 1871 and 1903. His data, reproduced here in figure 10.1, revealed an inverted U-shaped pattern: the annual number of foggy days in London rose during the 1870s and 1880s, reversed trend sometime around 1888 or 1889, and then fell steadily during the 1890s and early 1900s. Brodie attributed the rise and fall of the London fog to variation in the production of coal smoke. During the 1870s and 1880s, Brodie claimed, London businesses and homeowners burned coal with reckless abandon, filling the atmosphere with soot and giving rise to dense and dark fogs. After 1890, however, technological, legal, and social changes enabled, or forced, homeowners and businesses to burn coal more efficiently and cleanly. In particular, the expansion of gas for heating and cooking, and electricity for lighting curtailed domestic sources of smoke, and the London Coal Smoke Abatement Society lobbied local authorities to enforce the Public Health Acts, which required manufacturers to adopt low-smoke technologies (Brodie 1905, 15–20).

In this chapter, we evaluate Brodie's claim using more data than he had access to at the time and modern econometric techniques. Three types of evidence will be considered. First, evidence on foggy days and coal con-

Karen Clay is an associate professor of economics at Carnegie Mellon University, and a faculty research fellow of the National Bureau of Economic Research. Werner Troesken is a professor of economics at the University of Pittsburgh, and a research associate of the National Bureau of Economic Research.

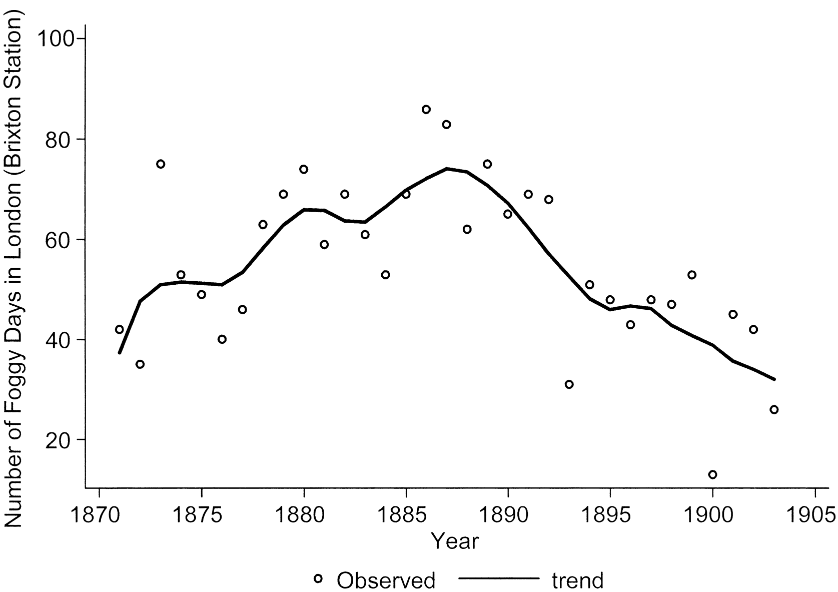

Fig. 10.1 Annual number of foggy days in London
Source: See text.

sumption are presented. Both are trending up over time, particularly after 1850. Second, we present a brief history of smoke abatement technologies and the enforcement of pollution control laws during the Victorian and Edwardian eras. This history will help establish a circumstantial case that such actions helped make London a less smoky place. Third, using a procedure we describe as a reverse-event study, we use large and unusual spikes in weekly mortality data to identify the frequency and severity of fog-related events. Fog-related events were severe and persistent episodes of fog that culminated in spikes in mortality, particularly from respiratory diseases. The reverse event study is a centerpiece of the chapter, and the most novel part of our analysis. The results suggest that by the early twentieth century, fogs and the associated spikes in mortality had largely abated.

The ostensible rise and fall of the London fog should interest economists and economic historians on at least two levels. First, the debate surrounding Brodie's paper prefigures current debates about the environmental Kuznets curve (EKC). Second, the basic question Brodie raised is of no small historical moment: how could there have been a meaningful environmental movement in Victorian England? We tend to think of Victorian Britain as a place where the expedience of cholera and child labor trumped the expense of clean water and a decent wage, as a place where environmental and social degradation served as the handmaidens of avarice and economic development. Yet Brodie's paper suggests something quite different, as does even a cursory look at the political and economic history of smoke abatement.

The chapter also has implications for understanding climate change. First, it shows that industrialization can change climate and that this type of climate change can sometimes be reversed by reducing pollution levels. Second, one can speculate on the effect that current global warming would have had on London had it occurred during the late nineteenth and early twentieth centuries. Global warming would probably have reduced toxic fogs in two ways. First, it would have reduced coal consumption. Second, it would have increased the number of days above 40 degrees. Above 40 degrees, the fog was less likely to form. At the same time, warming would likely have exacerbated other issues such as water quality, which was generally poor and considerably worse in the summer. Very little evidence exists on this trade-off, but it is important to recognize that there was a trade-off.

10.2 Coal and Fog

Figure 10.2 shows that the number of foggy days in London appears to have risen with per capita coal consumption. The first series, given by the small hollow circles, is the number of foggy days in London from 1730 to 1910. The second series, given by the small black circles, is coal consumption

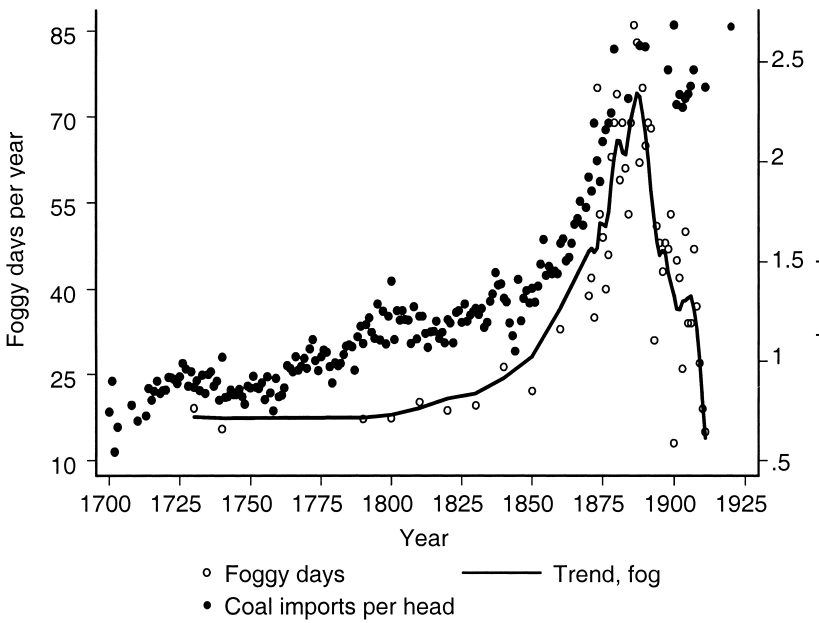

Fig. 10.2 Coal consumption per capital and foggy days in London, 1700–1925

Sources: The coal data are from the 1899, 1908, and 1919 volumes of *The Coal Trade* by Saward; the *Times* (July 23, 1901, 11; December 1, 1913, 26; August 11, 1927, 20); *Nature* (November 5, 1891, 12); and for earlier years, Mitchell (1988), a source which also provides data on London's population. The fog data are derived from the sources described in the text, especially Brodie (1891, 1905) and Mossman (1897).

per capita. We use imports of coal into London as a proxy for consumption. Nearly all coal imported into London was consumed there. Before 1800 and the Industrial Revolution, the number of foggy days in London is stagnant, hovering around twelve days per year. Coal consumption per head shows only slight growth during the same period. After 1800 and the onset of industrialization, both series begin to rise, and after 1850, the growth is exponential. The foggy days measure rises threefold between 1850 and 1890, increasing from around twenty-five to more than seventy-five days per annum. Similarly, annual coal consumption rises by a factor of 2.5, from one ton per head in 1850 to 2.5 tons in 1890. Things change abruptly for both series around 1890. Foggy days per annum reverses trend and plummets by around 85 percent within a twenty-year interval. Although coal consumption does not reverse trend, it stagnates, showing no growth over the next thirty years.

One important concern about the fog data is that it is noninstrumental. That is, the individual collecting the data went outside and made a subjective determination about whether it was foggy. Other series, which are available over shorter time periods, show similar trends in fog. Brodie's original series was for the Brixton station, which was located five miles south of the Thames. Data is available for a second station, West Norwood, which was another ten miles south. The qualitative patterns are very similar. Fog data compiled by Lempfert (1912) also shows similar patterns. Lempfert's instrumentally collected data on sunshine, which we will discuss shortly, also support these basic patterns.

The renowned nineteenth-century scientist Rollo Russell attributed the length and severity of the fog to coal consumption. According to Russell, the London fog began early in the morning around 6:00 a.m., when the city, or parts of the city, were enveloped by an "ordinary thick white fog." Soon after this, the city would awaken by lighting "about a million fires." These fires charged the atmosphere with "carbonaceous particles," which upon cooling, attached themselves to the spheres of water that constituted the fog. Ordinarily the warmth of the sun would have quickly dissipated the fog, but the smoke and an oily tar that surrounded the spheres of water impaired this process. In these conditions, city residents would not have sunlight until noon.[1] In an article in *Nature,* W. J. Russell (1891, 11) developed a similar line of thought, arguing that coal and sulphur particles induced the formation of fog by offering gaseous water a surface on which to condensate.[2]

1. This passage quoting Russell is from Hann's *Handbook of Climatology* (1903, 78). A similar description is offered in Russell (1906).

2. Russell (1891, 11) wrote, "The dust always present in the atmosphere offers this free surface to the gaseous water, and thus induces its condensation. This specific action of dust varies very considerably, first with regards to its composition, and second with regard to the size and abundance of the particles present. Sulphur burnt in the air is a most active fog producer, so is salt." For a similar statement regarding the origins and persistence of smoke-laden fogs, see Frankland (1882).

Late twentieth century scientists concur. For example, Brazell (1968, 102) writes, "London fogs are particularly obnoxious because the fog droplets tend to form on minute particles of atmospheric pollution which are usually produced by the combustion of coal, oil, and petrol."

With or without the coal smoke, though, London would have been subjected to much ordinary fog. Two government reports issued in the early 1900s showed that the formation of fog in London was correlated with temperature, humidity, and wind speed. Fogs were much more likely when the temperature in the city was below 40 degrees (no dense fog was observed when temperature was above 40), when humidity was high, and when the winds were calm.

Britain's "latitudinal and continental position" was of special importance because it left the whole country in the path of sequences of "migratory depressions" and anticyclones (Chandler 1965, 35). Anticyclones, and the temperature inversions that accompanied them, played a central role in the propagation of a certain kind of London fog. A short article in the journal *Notes and Queries* (March 2, 1878, 178) provides the clearest contemporary statement we have found on the significance of anticyclones. We quote it in full:

> These fogs are not caused by the rarefaction of the air, or by the consumption of gas, nor yet by the hills on the north, nor by the river. The peculiar atmospheric condition termed an anti-cyclone is the real cause of these annoying visitations; the wind is then blowing round a well defined circle, in the centre of which the air is tranquil, and consequently the smoke, condensed vapours, & c., cannot escape as they do when there is a direct onward movement of the wind. The pressure of the atmosphere at such times is almost invariably greatly in excess of the average in the midst of the anti-cyclone, which, by preventing the rise of the smoke, & c., increases the intensity of the fog. Whenever, therefore, an anti-cyclone occurs with London at or near the centre, there must necessarily be a "London fog," the density of which will be in proportion to the smoke evolved at the time. The same phenomenon may be observed in other places within the anticyclonic circle, but of course in a less degree of density.

A 1910 *Times of London* article argued that air quality had improved significantly. "Visitations" of smoke-laden fogs were "rare" by 1910 and "seldom" continued "without intermission for more than two or three days." The opening paragraph began with the reporter's own assessment of the situation, an assessment he clearly believed was unassailable:

> The decrease in recent years, not only in the frequency but in the intensity of London fog, is a matter which admits no serious question. Persons who have reached middle age well remember the time when dense smoke fogs of the worst possible description were a common feature of the winter season, and lasted not infrequently for a week or more at a stretch.

The same article also presented data on the hours of bright sunshine in London, which presumably would have been inversely correlated with the incidence of fog. Sunshine, in contrast to fog, was measured instrumentally using a device known as the "Campbell Stokes Sunshine Recorder." The recorder consisted of a clear ball that magnified bright sunlight and gradually burned away a piece of cardboard. The sunshine data found in the *Times* are broadly consistent Brodie's data on the fog; they suggest that improvements in London's air began five to ten years earlier, during the early to mid 1880s as opposed to the early 1890s (*Times,* December 27, 1910, 11).[3]

Contemporary observers agreed that London was becoming less smoky and foggy, but disagreed as to why. The *Times* article subscribed to Brodie's view:

> The diminution of smoke which has taken place within recent years may be attributed in a large measure to a more vigorous enforcement of the smoke prevention clauses of the Public Health Act, but it has in all probability been materially aided by the increased use of gas fires for both heating and cooking purposes, and also by improved methods of lighting (*Times,* December 27, 1910, 11).

Russell, in contrast, emphasized London's changing geography and broader weather patterns that were affecting the entire south of England. For Russell, the declining incidence of fog was not unique to London fog, but common to all cities and towns in the region.

R. G. K. Lempfert an accomplished climate scientist and the superintendent of the Forecast Division of the Royal Meteorological Office presented evidence on regionwide weather patterns. "It is my object," he wrote (1912, 23), "to examine the statistics of bright sunshine for London and other large towns to see whether they afford evidence of progressive amelioration or the reverse of the smoke nuisance." Lempfert's identification strategy was simple. If London's atmosphere was becoming more sunny because of purely meteorological phenomena, those same phenomena would have affected surrounding rural areas as well. If, however, London's atmosphere was improving because of innovations (both regulatory and technological) unique to metropolitan areas, London would have become increasingly sunny relative to the neighboring control areas. Furthermore, because far

3. This was not the first time that the *Times* argued that London's atmosphere was becoming cleaner. In an editorial published a few months before Brodie's paper, the *Times* (December 24, 1904) wrote, "we think no one whose experience of London extends over many years can entertain the slightest doubt that the fogs of the present day, even the worst of them, are definitely less filthy and less opaque than those of the early or middle Victorian period. The change is commonly, and perhaps right, attributed to the extent to which the production of smoke in the metropolis has been diminished by legislation." See also, Schlicht (1907, 685), who in an article published in the *Journal of the Society of Arts,* wrote, "It must be said . . . that in recent years, thanks to admirable efforts of the Coal Smoke Abatement Society, and the exploitation of gas as a substitute for coal by the gas companies, the atmosphere of London is much less offensive than it was twenty-five or thirty years ago."

Table 10.1 **Duration of bright sunshine at London stations as a proportion of the duration at neighboring country stations**

	(London)/(country)		(Kew)/(country)		(London)/(Kew)	
Interval	Winter	Summer	Winter	Summer	Winter	Summer
1881–1885	.17	.83	.85	.97	.20	.84
1886–1890	.29	.85	.89	.96	.32	.87
1891–1895	.32	.95	.83	1.02	.39	.94
1896–1900	.35	.89	.97	1.03	.36	.86
1901–1905	.32	.93	.88	1.04	.37	.89
1906–1910	.38	.92	.81	.99	.46	.92

Source: Lempfert (1912, 25).

more coal was burnt during the winter months than the summer, if reductions in coal smoke were driving the improvement in London's atmosphere, one should observe greater relative improvement when we restrict the sample to the winter (Lempfert 1912).

Lempfert's data, which are reproduced in table 10.1, suggest that weather patterns were relatively stable. In first two columns of data, the table expresses the duration of bright sunshine at two London weather stations (Westminster and Bunhill Row) as a proportion of the duration at four nearby "country" stations (Oxford, Cambridge, Marlboro, and Geldeston). Notice that for the first five-year interval, 1881 to 1885, London in the winter enjoys only 17 percent of the sunshine experienced in the control areas; by the last five-year interval, 1906 to 1910, London's relative sunshine rate has more than doubled, to 38 percent. There is evidence of improvement during the summer—the relative sunshine rate grows from 83 to 92 percent—but the improvement is much less pronounced than that observed during the winter months. The third and forth columns of data perform the same experiment for the weather station at Kew Gardens as the (placebo) treatment. The Kew station resided on the western edge of London (today, about ten miles directly east of Heathrow Airport) and was relatively immune from the smoke problems that plagued the rest of the metropolis.[4] Kew shows little relative improvement in the duration of sunshine, in either winter or summer. The final two columns of data compare sunshine at the city stations to that observed at the Kew station. As when the country stations were used as controls, there is evidence that the city stations became increasingly sunny relative to the station at Kew. Again, the improvement is concentrated in the

4. The word "relative" is important. Kew was not entirely immune from the effects of London smoke, and there is a small literature that documents how the gardens were adversely affected by the city's production of coal smoke. See, for example, J. W. Bean's article "A Note on Recent Observations of the Smoke Nuisance at Kew Gardens," presented at Coal Smoke Abatement Conference in 1912.

winter months, with the relative sunshine rate rising from 20 to 46 percent during the winter and from 84 to 92 percent during the summer.[5]

10.3 Victorian Environmentalism

Figure 10.3 plots the natural log of tons of coal imported into London, which is a measure of total coal consumption over time. The observed log is plotted by the empty circles. A vertical reference line is plotted at the year 1890. Figure 10.4 also includes several trend lines that identify changes in slope over different historical intervals. Together with figure 10.1, figure 10.3 shows that coal imports were increasing rapidly overall and in per capita terms. Not until sometime after 1890 does this pattern of increasing growth cease. There is clear evidence that after this point, for the next thirty years, coal consumption is well below trend.

The patterns in figures 10.1 and 10.3 seem broadly consistent with Brodie's explanation of the rise and fall of the London fog. When coal consumption in England grew slowly, and in some absolute sense, was not large, London fogs were much less frequent than they would later prove to be.

The data at the end of the period are problematic, however. How could stabilization in the per capita consumption of coal initiate a decline in fog? If increases in coal consumption per capita drove the increase in fog, the converse—that a decline in coal consumption in per capita drove the decrease in fog—would also have to be true, would it not? Moreover, to the extent that smoke density was determined solely by the amount of coal consumed, one should not even bother looking at coal consumption per head; all that should matter is total consumption of coal. By this logic, a reduction in smoke required a reduction in the total amount of coal consumed.

We think that three changes reduced the effect of coal, in the absence of declines in consumption. The first change involved dispersing people and smoke over a larger area, in effect, diluting the smoke. The second change involved the Public Health Act. This law empowered police in metropolitan London to fine manufacturers throughout the area for dense smoke emissions. Enforcement of this law encouraged firms to conserve on soft coal. It is important to emphasize that none of this need to have been rational or profit maximizing from a given firm's perspective. Logic suggests it must have cost firms more to economize on soft coal than the coal was worth; otherwise, they would have adopted smoke abatement technologies and

5. Lempfert (1912, 27–28) offered a caveat regarding instrumental measures of bright sunlight. The glass balls employed in the Campbell-Stokes recorders began to yellow and became less sensitive to sunlight with time. Lempfert argued that this would lead observers to understate increases in the incidence of bright sunlight in London. Unfortunately, it would also have had the same effect in the control counties. Lempfert suggested that, whatever the bias, these effects would have been small and that officials took steps to minimize the resulting measurement errors. Nevertheless, the caution should be noted.

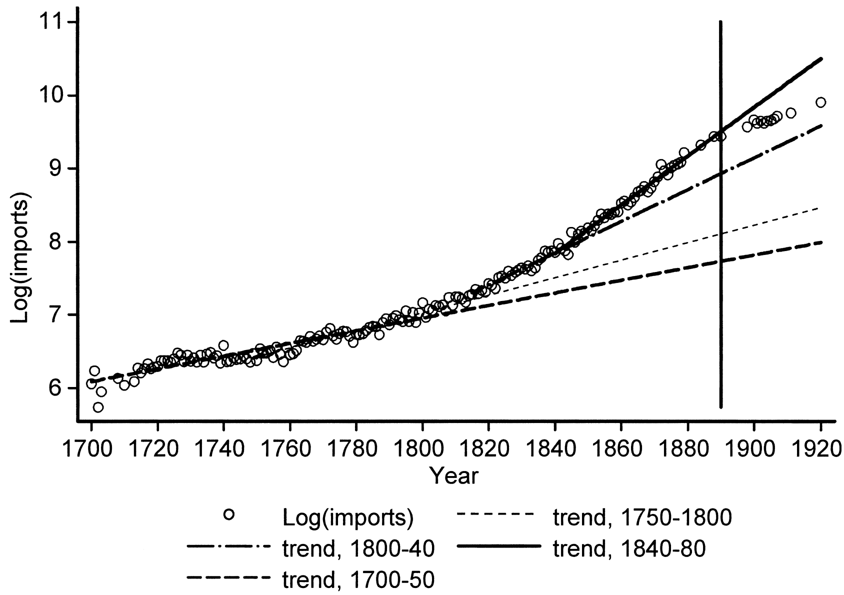

Fig. 10.3 Total coal consumption in London (in logs), 1700–1920
Source: See note to figure 10.2.

practices without the impetus of the Public Health Act. The third change involved households. Complementing the actions of manufacturers, London homeowners also became more cognizant of ways to conserve on coal and adopted gas for cooking and heating or purchased grates and boilers designed to minimize smoke emissions and wasted fuel.

10.3.1 Population Redistribution

As population increases, the amount of coal consumed rises, which, in turn, increases the absolute amount of smoke and smoke density. But there is also a countervailing effect. As population increases, so, too, does the area of the city. New migrants do not only move to previously settled areas of the city; they also take up residence in outlying areas that were previously unsettled. Redistributing population from a densely populated core to a less densely populated periphery would also change the distribution of smoke.

Before continuing, we need to more clearly define what is meant by the geographic descriptor "London." Today, London proper covers only 1.2 square miles; Greater London covers nearly 660 square miles. Thus far, all of our references to London have been to Greater London. We will continue this practice, but will also draw the distinction when appropriate. We did not raise this fine point of urban geography earlier because it was not relevant until now.

Fig. 10.4 Population density in London proper and Greater London, 1801–2001
Source: Poore (1883) for nineteenth century; *London Statistics* various years.

Figure 10.4 shows the reallocation of population in London over time. It plots population density in London proper (the core) and the whole of Greater London from 1811 through 2001. Population density in London proper starts the series at a remarkable 400 persons per hectare and holds steady there until 1861, when it implodes. By 1911, population density in London proper falls to 103.6. Population density for Greater London rises from .6 persons per hectare in 1811 to 1.44 in 1861, after which it begins a more rapid ascent. By 1911, population density in Greater London rises to 3.5. These data suggest that one path to solving London's smoke problem began to emerge three decades before Brodie's inflection point around 1890. Poore (1893) indicated that it was not just London proper that experienced an outflow of people. The combined population of all five of London's central districts—Holborn; The Strand; St. Martins; St. Giles; and the city proper—dropped from a peak of 334,369 in 1861 to 247,140 in 1891.[6]

By driving people out of the center of the metropolis, the dense, smoky fogs of central London might have contained the seeds of their own demise. An article published in *Science* more than a century ago explained. Asking why the population density of Paris was so much higher than that of London, the unnamed author wrote (February 19, 1886, 173–74):

6. Poore (1893), it should be noted, believed that the increase in the area of the city was a cause of fogs.

> The average density of Paris is more than double that of London, and yet the streets are brighter and cleaner. The question probably turns more upon the prevention of smoke than any thing else. If the fog and gloom could be removed, and free access provided for the sunlight, there is no pleasanter [sic] or healthier place to live than the west end of London; and many who now endure, morning and evening, forty minutes' journey through choking tunnels, and walk long distances to railway termini, would stay in town if they could be relieved from the depression which is the accompaniment of a murky atmosphere.

10.3.2 Law and Changing Technology

Although London had a long history of antismoke agitation (see Brimblecombe 1987, 10–18, 90–107), the movement began in earnest in 1880 with the creation of the National Smoke Abatement Institution (NSAI). A private institution located mainly in London but with ties throughout the United Kingdom, the NSAI organized exhibitions for inventors and manufacturers to display heating and cooking grates, stoves, steam boilers, smokeless fuels, and other devices designed to mitigate emissions of coal smoke. The group offered prizes for inventions deemed especially promising and created venues through which it sought to instruct manufacturers and homeowners in ways to conserve on coal. It also worked to dispel the widespread notion that coal smoke had disinfectant properties that destroyed airborne pathogens that would have otherwise carried diseases like tuberculosis and influenza (*Report of the Smoke Abatement Committee* 1883, 183; *Nature,* February 9, 1888, 356–68; *Transactions of the Sanitary Institute of Great Britain,* 1887–1888, 301–45).

The members of the NSAI, like most participants in the late-nineteenth-century smoke abatement movement, embraced an early incarnation of the Porter hypothesis, the idea that environmental regulations and controls might spur productivity advances. The NSAI believed that the technologies it recognized and helped introduce to the world would not only make nineteenth-century cities cleaner and less polluted, they would make businesses more efficient and profitable. Arguing that dense smoke represented imperfect combustion and wasted fuel, the advocates of this early Porterism claimed that proper stoking methods, specially designed coal grates, stoking machines, and various types of smoke consumers would enable manufacturers to conserve on coal (e.g., *Report from the Select Committee on Smoke Prevention* 1843; *Report of the Smoke Abatement Committee,* 1883, 183; *British Medical Journal,* August 20, 1908, 615).

The idea that proper stoking prevented smoke and saved coal has a long history and was widely accepted, even among producers and manufacturers who were otherwise resistant to smoke abatement. In a paper read before the *Royal Sanitary Institute,* Caborne (1906) expressed the identical argument. Twenty year earlier in front of the same venue, Fletcher (1887–1888) claimed to have stated the obvious when he discussed the efficacy of proper stoking. A survey conducted by the London Coal Smoke Abatement Society in the early 1900s also supports the idea that factory owners believed this to be true. Surveying sixty-three London factories who had not been cited for excessive smoke in the last six months of 1904, the society elicited thirty-five useful responses. Of the respondents, just over half (thirteen) ascribed "their success in preventing the emission of smoke to careful stoking" (Rideal 1906, 149).

Arguably the most important factor driving down pollution in the aftermath of the Public Health Act was the direct effect of having producers switch from soft coal to different varieties of hard coal. In the context of figure 10.2, the data on coal consumption per capita are for the consumption of all kinds of coal not just soft coal. We have found no data source that would allow us to construct separate times series for hard and soft coal. However, of the thirty-five firms responding to the aforementioned survey of the smoke abatement society, all but one used some variety of coke or anthracite. Seventeen firms used Welsh coal, a variety of anthracite (Rideal 1906). When miners in the south of Wales struck during the late 1890s, London factories that had been using Welsh coal were forced to use bituminous. Their furnaces ill-equipped for bituminous coal and unable to stoke their fires properly, the factory owners were "hauled up before sundry magistrates to show cause why they should not abate the smoke nuisance they [were] making" (Booth 1898, 1064; *Public Health,* August 15, 1898, 373).

In the absence of legislation punishing smoke emissions, it is difficult to imagine that manufacturers would have switched from soft to hard coal, which all reports indicate was "much dearer" than soft coal and harder to light (*Medical Times,* March 11, 1882, 395; Booth 1898; Saward 1914, 156; Reynolds 1882, 167–80). Figure 10.5 plots the relative price of Welsh steam coal and ordinary (Newcastle) bituminous coal over the course of the nineteenth century and early twentieth century. The underlying price series are based on the supply prices at the mine, not delivered prices in London. Over the long term, the relative price of Welsh coal sold at a 20 percent premium throughout the period. This pattern rules out the possibility that the switch from soft to English coal to "smokeless" Welsh coal was driven by a reduction in the relative price of Welsh coal. On the contrary, the trend line indicates a nontrivial uptick in the relative price of Welsh coal sometime after 1885. This pattern is consistent with the hypothesis that demand for smokeless coals increased relative to the demand for ordinary bituminous coal as a result of regulatory or political pressures.

As manufacturers switched from soft coal to hard, they also indirectly helped reduce overall coal consumption. Owens (1912, 93–94) provides a useful explanation of this mechanism. Because soot was a "very bad conductor of heat," when boiler plates became covered in soot, "the rate of heat transfer [was] reduced." Owens conducted a series of experiments to mea-

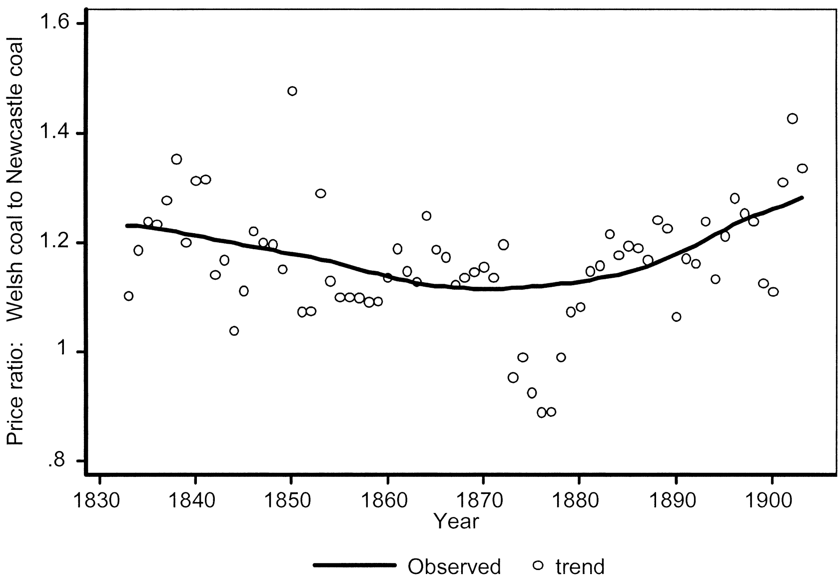

Fig. 10.5 Price of steam coal in Swansea (Wales) divided by price of bituminous coal in Newcastle

Sources: Price series are from Wright (1905, 409–20). Alternative price series that yield similar patterns can be found in Great Britain Board of Trade (1903, 12–19).

Note: Trend line estimated with STATA using a running line smoother, bandwidth of .8, and lowess option.

sure the amount of heat that might have been lost when factory owners and operatives allowed soot to build up on boiler plates. He found that a layer of soot 1/20 of an inch thick reduced the transfer of heat by 15 percent. One way manufacturers could prevent the development of coal soot on boiler plates was to use hard coal intermittently or mixed with the bituminous coal. Because Welsh and anthracite coals generated less soot and tar than bituminous coal, even their intermittent use delayed the formation of soot on boiler plates and enabled workers to generate more heat than they otherwise would have when they used bituminous coal alone. It was not uncommon for manufacturers in turn-of-the-century London to use a mixture of smokeless coal and bituminous coal (Rideal 1906).

Aside from the switch from bituminous to Welsh coal among manufacturers, there was also a more voluntary transition taking among consumers. An observer who placed heavy emphasis on the voluntary adoption of new technologies was Sir George Livesey, an officer of a large London gas company and leader of the city's smoke abatement movement. In a paper presented to the Royal Sanitary Institute, Livesey argued that London had become a less smoky place because more and more consumers, especially those among the working classes, were using gas stoves rather than coal for cooking. The spread of gas cookers among the poor was the result of two pricing strategies adopted by London gas companies: one was the practice of renting stoves to customers; the other was the coin-in-the-slot method of paying for gas. Of the 834,000 households in London that purchased gas from the city's three major gas companies, 70 percent used gas stoves for cooking, and that number would have been even higher if homes and apartments had had sufficient space for a gas stove and opposition from landlords had not been so strong (Livesey 1906). While one might dismiss Livesey's arguments and opposition to coal smoke as patently self-serving, ten years before he published his paper, the *British Medical Journal* (August 22, 1896, 465) published data and evidence very much in keeping with his otherwise partisan observations. Surprisingly the *British Medical Journal* suggested that it was the wealthy, not the poor, who were slow to adopt gas for cooking.[7]

10.4 Fog-Related Events: History, Identification, and Health Effects

London's most famous fog-related event occurred in December 1952 and is documented in William Wise's popular book *Killer Smog: The World's Worst Air Pollution Disaster.* The fog began on December 5 and did not lift for five days. Government officials estimated that there were roughly 4,000 excess deaths because of the fog, mostly due to respiratory complaints such as asthma and bronchitis.

7. The *British Medical Journal* (August 22, 1896, 465) wrote:

> A new and unexpected agency is having a most beneficial effect in contributing to the abatement of the smoke nuisance in London. The relative clearness of the London atmosphere within the last twelve months has been plainly apparent, and the smoke cloud which obscures the London atmosphere appears to be progressively lightening. Mr. Ernest Hart, Chairman of the Smoke Abatement Exhibition in London, frequently pointed out that the greatest contributors to the smoke cloud of London were the small grates of the enormous number of houses of the poor, and a great deal of ingenuity had been exhausted with relatively little success in endeavoring to abate this nuisance. The use of gas fires was urgently recommended, but had hitherto been difficult, owing to its cost and want of suitable apparatus. The rapid and very extensive growth of the use of gas for cooking as well as lighting purposes by the working classes, due to the introduction of the "penny in the slot" system, is working a great revolution in the London atmosphere. During the last four years, the South London Gas Company alone has fixed 50,000 slot meters, and nearly 38,000 small gas cooking stoves in the houses of the working man. This movement is still making great progress, and we hope means may be found to extend it to the houses of the more comfortable classes. The enormous improvement in the London atmosphere, and the clearing away of a smoke pall which hangs over London, may then be anticipated.

See also Ackermann (1906), who pleaded with London officials to promote the spread of producer gas (a cheap, low-grade type of coal gas appropriate for heating and cooking but not lighting) to replace coal. Martin (1906) presented data to indicate the threshold price at which it would be economical for households to switch from coal to producer gas. Fifteen years before the article in the *British Medical Journal,* Alfred Carpenter, an independent scientist, proposed heavily taxing coal use in London, thereby encouraging homeowners and manufacturers to adopt gas for lighting, heating, cooking, and mechanical propulsion. See Carpenter (1880).

Although we might know this event best, that does not necessarily mean it was the worst. Earlier fogs lasted longer, and there is evidence that they took a heavier death toll. For example, the aforementioned cattle-show fog of 1873 lasted a week (Brazell 1968, 111). The December fog of 1879 lasted nearly two weeks, darkening London's skies from December 3 through December 27 (Brazell 1968, 111; Scott 1896). There was also the aptly named "anticyclonic winter" of 1890 to 1891, a two-month interval of almost uninterrupted fog (Brodie 1891). Estimates presented in the following suggest that this event generated 7,405 excess deaths, nearly twice the number of excess deaths observed during the winter of 1952.

10.4.1 History

Imagine London in the late nineteenth century during a fog. Although it is noon, the city is as dark as night. People must uses torches just to see a few yards ahead of them. Horse-drawn carriages cannot move; trains crawl at a snail's pace, and, in some instances, cease operating. People described the darkness as fog because it was wet and heavy and because it almost always occurred during unusually cold and calm conditions when fog was otherwise common. But it was also more than just fog. The darkness burned the eyes and throat.

Deaths from all causes, but especially bronchitis and other acute respiratory diseases, spiked during such dense fogs and immediately after they lifted. First-hand observers blamed the coal smoke trapped in the fog: "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 that dark expectoration which was so injurious to the constitution; it gathered on the lungs and there accumulated" (*Times,* February 7, 1882, 10). Another observer wrote (*Medical Times,* March 11, 1882, 395), "After a fog the nostrils are like chimneys, and are lined with a layer of black smut. The expectoration is black from the amount of carbon arrested in the mucus of the air passages. For a day or two after exposure to a smut-laden atmosphere, black phlegm is brought up." During a cattle show in 1873, the fog was so thick that the Queen's prize bull dropped dead, as did several other large animals. If all this were not enough, imagine, too, that the fog went on for days at a time and, in some extraordinary cases, weeks. Although a composite of several of the most famous London fogs, these images convey what it was like to experience the most dense and persistent ones.[8]

8. This composite is based heavily on a report in the *Times* (February 6, 1882, 7). The quotation is from a talk by Dr. J. M. Fothergill recorded in the *Times* (February 7, 1882, 10). Other articles in the *Times* that corroborate this picture, include January 21, 1861, 9; November 19, 1862, 6; and November 26, 1858, 10. That the Queen's prize bull was killed raises the question about how the monarchy and elite groups responded to the fog. Centuries before the Public Health Act was passed in 1891, the King had barred the burning of coal in London, and wealthy elites were at the forefront of smoke eradication; poorer groups were less concerned or opposed. This cross-sectional pattern is consistent the modern EKC and, in a political

After a severe fog in early February of 1882, the *Times* (February 13, 1882, 10) published the results of the coroner's inquest into several fog-related deaths. The results provide a window into the physiological mechanisms that made some fogs so deadly. James Smith, aged sixty, was a wheelwright who had been "had been suffering from chest affection some time past." Although his wife "begged him" not go out in the fog, he went out anyway. When he returned, he was "very ill," and he died a few days later. The coroner ruled that "the fog had hastened his death very materially, increasing and developing bronchitis to an alarming extent." Alice Wright, aged sixty-six, went out when the "fog was the thickest, to fetch her mangling." Twenty minutes later, a passerby found her lying in a passage and ran into the home to search out her daughter. Finding Wright unconscious, the daughter brought her inside and called for a doctor, "who found the poor creature dead." The postmortem "showed that the fog had brought on effusion on the brain." William Henry Pepper, aged three months, was the son of a blacksmith. Although he had been a healthy baby, he took ill after he and his mother had ventured into the fog. The coroner concluded that "the child's lungs" were "too weak to resist the poison which had filtered into them." "Bronchial pneumonia" set in and "death resulted."

For convenience, we refer to extreme conditions like those just described as a "fog-related event." Fog-related events were an extreme form of smog. The available evidence indicates that they were associated with anticyclones and temperature inversions (Brodie 1891; Scott 1896; *Times,* December 13, 1873, 7; Wise 2001, 15–18).

As the preceding discussion suggests, a defining features of a fog-related event is an unusually large number of deaths, especially from acute respiratory diseases. One of the clearest contemporary statements on the spike in death rates that accompanied fog-related events comes from a short article in the *British Medical Journal.* The article described an event that occurred in February of 1880 (February 14, 1880, 254):

> If one or two weeks during the cholera epidemic of 1849 and 1854 be excepted, the recorded mortality in London last week was higher than it has been at any time during the past forty years of civil registration. No fewer than 3,376 deaths were registered within the metropolis during the week ending Saturday, showing an excess of 1,657 upon the average number in the corresponding week of the last ten years.

Of these deaths, most were attributable to respiratory diseases, particularly bronchitis:

> The excess of mortality was mainly referred to diseases of the respiratory organs, which caused 1,557 deaths last week, against 559 and 757 in the two preceding two weeks, showing an excess of 1,118 upon the corrected

economy sense, sounds plausible. To the extent that the costs of smoke eradication were born disproportionately by the poor, one would expect that the wealthy segments of society to have been the primary advocates environmental improvements.

weekly average. The fatal cases of bronchitis, which had been 531 in the previous week, rose to 1,223 last week.

The last time the weekly death rate in the metropolis had approached these levels was during the cattle-show fog of 1873.

10.4.2 Identification

Ideally, we would like to have a complete history of all of the fog-related events in London during the late nineteenth and early twentieth century. If we possessed such a history, and that history was independent of Brodie's fog observations, we could look at the frequency and severity of fog-related events before and after 1890. If Brodie's data were correct, we would expect to observe increasing frequency and severity in the years leading up to 1890 and decreasing frequency and severity in the years following. The difficultly, however, is that there is no formal history of fog-related events in London that claims to be comprehensive in any sense. The question, then, is how to construct such a history. One approach might be to return to the records of the Royal Meteorological Office (which Brodie used) and search for extended periods of dense fog. This approach is problematic: there were periods of persistent and dense fog in London that were not associated with unusually high mortality and would not fall under our definition of a fog-related event. As an alternative strategy, one might scour the *Times* of London and other contemporary news outlets for articles that described phenomena consistent with fog-related events. Besides the high search costs and subjectivity of this approach, one could never be certain of identifying all relevant events.

The *British Medical Journal* article discussed in the preceding suggests an econometric strategy for identifying events. The article observed that deaths spiked during the weeks associated with fog-related events and that these spikes were large and uncommon. Our identification strategy is an event study in reverse: we use spikes in the data to predict events, as opposed to using events to predict spikes in the data. To implement this strategy, we proceed as follows. We first collect weekly data on deaths in London during the late nineteenth and early twentieth centuries and calculate the weekly crude death rate. Using a simple regression framework—the weekly crude death rate is regressed against a few control variables—we then estimate a predicted death rate for the each of the weeks in our sample. From there, it is a simple matter to calculate a residual death rate for each week. The value of the residual establishes a necessary, but not a sufficient, condition to qualify as an event week. In particular, to be coded as an event week, the week must satisfy the following three conditions:

(c.1) The residual death rate for the week must exceed .1. The choice of .1 as a threshold is not entirely arbitrary. Residuals above .1 are rare—they are 1.1 percent of the total sample—and as shown in the following, they are probably generated by a different set of forces than those below the threshold.

(c.2) There must be supporting qualitative evidence in the *Times* indicating the presence of unusually dense and persistent fog during the week or sometime in the preceding week.
(c.3) The preponderance of evidence must suggest that the spike of was not caused by something other than fog, such as an epidemic disease like cholera or influenza. If the weight of the evidence suggests an epidemic disease was present and important, the week is coded as a nonevent week. The online catalogues of the *British Medical Journal* (at PubMed Central) and the *Times* are searched for such evidence.

As reported in the following, there are thirty-two weeks out of the sample that satisfy all three of these requirements and are coded as event weeks.

The data on deaths per week are gathered from the *Weekly Returns of the Registrar General,* which recorded deaths for several of England's largest cities including London. For years when the published volumes of the Registrar General are unavailable, the *Times* is consulted. After 1888, the *Times* regularly summarized the weekly returns of the Registrar General.[9] Death rates are calculated as deaths per 1,000 persons and are constructed using interpolated population data from Mitchell (1988, 673). Note that we calculate and report a true weekly death rate, not an annualized weekly death rate. The sample period covers the fifty-five-year interval extending from 1855 to 1910, yielding a maximum possible sample size of 2,860 (52 × 55). There are, however, twenty-five weeks for which data are unavailable. Dropping these from the sample, 2,835 observations remain.

Basic plots suggest that toxic fog was having an adverse effect on the health of Londoners, even as mortality rates were falling. Figure 10.6 plots the annual crude death rate in London, which is falling steeply over time. Figure 10.7 plots deaths from respiratory diseases and bronchitis in London from 1850 through 1920. Of the two series, we believe the bronchitis series is superior because bronchitis is more closely correlated with fog and inorganic pathogens. Pneumonia and tuberculosis, which have bacterial and viral origins, have weaker connections (Lawther 1959; Schaefer 1907; White and Shuey 1914). We include the latter series only because one might question the ability of nineteenth-century physicians to distinguish among the three diseases. The difference between figures 10.6 and 10.7 is quite striking. The crude death rate is falling, yet the deaths from respiratory diseases are high up to 1880, when they begin to fall. Bronchitis deaths appear to be increasing until the late 1870s and remain high through 1890, when they begin to fall.

We estimate the following model:

$$d_{kt} = \alpha + w_k\beta_1 + y_t\beta_2 + \beta_3 N + e_{kt}, \tag{1}$$

9. England's death registration system began in 1836 and included provisions that fined those who failed to report deaths.

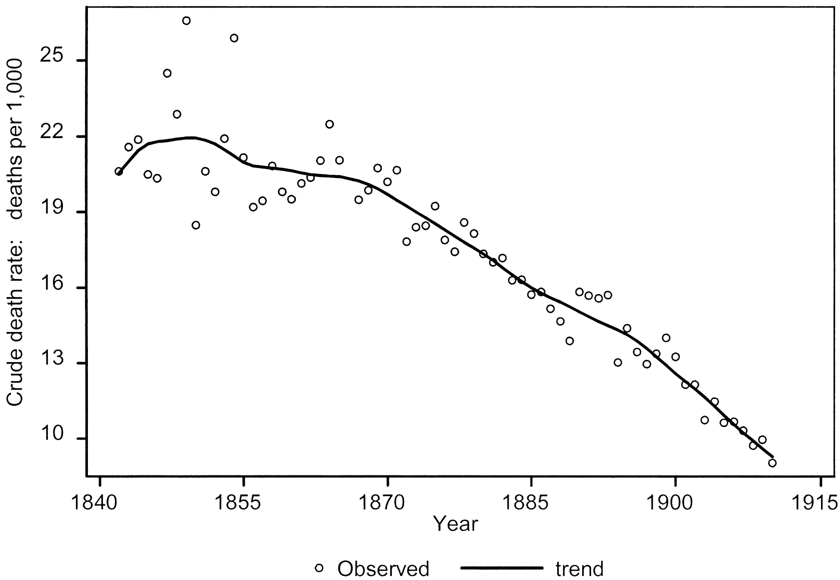

Fig. 10.6 Crude death rate in London, 1840–1915

Sources: Annual Reports of the Registrar General (England and Wales), various years; and *London Statistics,* various years.

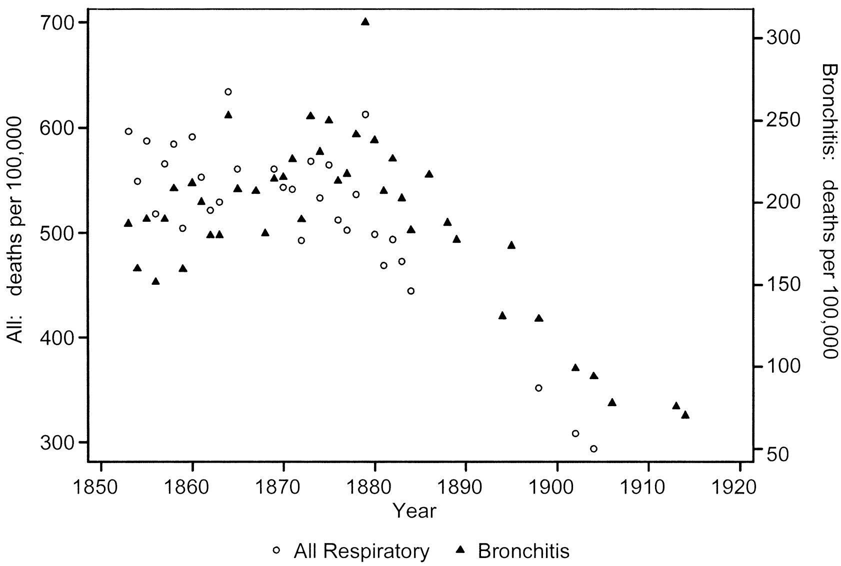

Fig. 10.7 Deaths from respiratory diseases in London, 1850–1920

Sources: Annual Reports of the Registrar General (England and Wales), various years; and *London Statistics,* various years.

Note: The category "all respiratory" includes pneumonia, phthisis (tuberculosis), and bronchitis.

where d_{kt} is the overall death rate in London in week k ($k = 1, 2, \ldots, 52$) and year t ($t = 1, 2, \ldots, 55$); w_k is a vector of week dummies; y_t is a vector of year dummies; N is an overall time trend ($N = 1, 2, \ldots, 2{,}860$); and e_{kt} is a random error term.[10]

Table 10.2 identifies the thirty-two weeks in the 1855 to 1910 interval that satisfy the conditions necessary to be designated as an event week. The first two columns indicate the year and the week of the year in which the event took place. The final column, labeled documentation, provides citations to the month, day, and page of the *Times* corroborating the presence of a fog-related event. If the event has already been described in the secondary literature on the London fog, citations to representative secondary sources are provided. The third column, labeled "known," indicates whether the secondary literature already describes the weeks as involving fog-related events. Of the thirty-two event weeks, twenty-two are part of a sequence of continuous weeks. Events 1 and 2 involve the fourth and fifth weeks of 1855, events 3 and 4 involve the forty-seventh and forty-eighth weeks of 1858, and so on. The longest sequences are five weeks (events 22 to 26) and four weeks (events 29 to 32). The last event occurs in the second week of 1900. After that time, fog-related events cease for the period covered by our sample, which as said in the preceding ends in 1910.

The results are robust to changes in our criteria that define event weeks. If, for example, we drop conditions (c.2) and (c.3), the same basic patterns and substantive conclusions emerge. The results are also unchanged if we lower or raise the residual threshold by a modest amount.

It is notable how few of the event weeks we identify have been identified by the extant literature. For the period between 1855 and 1872, the reverse event study yields ten previously unknown events. The descriptions of these events found in the *Times* suggest the procedure is onto something. Describing events 6 and 7, the *Times* (January 21, 1861, 9) observed:

> Last Thursday week, when the whole of the metropolis was enveloped in a dense fog, large numbers of person [*sic*] were stuck down as if shot. Dr. Lotheby, in his report to the city . . . says 'the quantity of organic vapour, sulphate of ammonia, and finely divided soot in the atmosphere was unprecedented.'

The *Times* (November 19, 1862, 6) characterized the fogs associated with event 8 this way: "There was a dense fog on Tuesday night, and on Thursday

10. Ideally, it would be desirable to analyze data on cause-specific death rates for respiratory ailments such as bronchitis and pneumonia. Although we believe these data are available, the source in which they are reported is not easily obtained. We hope to acquire this source and analyze cause-specific death rates in subsequent research. Nevertheless, the anecdotal evidence presented elsewhere in the chapter indicates that spikes in mortality were driven by respiratory diseases.

Table 10.2 Fog-related events identified by reverse event study, 1855–1910

Year	Week	Event no.	Known[a]	Documentation (*Times* unless otherwise indicated)
1855	4	1	No	1/15, 10; 2/1, 5
1855	5	2	No	2/5, 10
1858	47	3	No	11/17, 10
1858	48	4	No	11/26, 10
1859	52	5	No	12/19, 6; 12/20, 10; 12/21, 12; 12/30, 9; 1/8, 6
1861	3	6	No	1/11, 9; 1/16, 10
1861	4	7	No	1/21, 10; 1/23, 12
1862	48	8	No	11/15, 11; 11/17, 10; 11/19, 6; 12/3, 12
1864	3	9	No	1/13, 12; 1/22, 12
1871	50	10	No	11/18, 9; 11/19, 8; 12/20, 6
1873	51	11	Yes	12/19, 10; Brazell (1968, 111)
1874	48	12	No	11/23, 5
1874	49	13	No	12/2, 10
1874	52	14	No	12/25, 7; 12/28, 5
1875	1	15	No	1/1, 11; 1/8, 9
1879	51	16	Yes	12/17, 8; Scott (1896); *Nature* (November 5, 1891, 13)
1880	5	17	Yes	*British Medical Journal* (February 14, 1880, 254); *Nature* (November 5, 1891, 13)
1880	6	18	Yes	Same as above
1882	6	19	No	2/3, 6; 2/6, 7; 2/7, 10; 2/13, 10
1890	2	20	Yes	*Nature* (November 5, 1891, 14–15); Brodie (1891)
1890	3	21	Yes	Same as above
1892	1	22	Yes	*Nature* (November 5, 1891, 14–15)
1892	2	23	Yes	Same as above
1892	3	24	Yes	Same as above
1892	4	25	Yes	Same as above
1892	5	26	Yes	Same as above
1893	49	27	No	11/23, 8; 11/30, 8
1894	2	28	No	1/8, 6; 1/15, 6
1899	51	29	Yes	12/1, 11; 12/2, 5; 12/4, 13; 12/13, 11
1899	52	30	Yes	12/23, 12; 12/28, 5
1900	1	31	Yes	1/3, 8; Brazell (1968, 111)
1900	2	32	Yes	Same as above

Sources: See text and final column of table.

[a]"Known" indicates whether the secondary literature already describes the weeks as involving fog-related events.

afternoon fog prevailed of a density that has not been equaled for several years." Of events 3 and 4, the *Times* (November 26, 1858, 10) said, "it has been several years since we have seen so dense a fog." Events 12 through 15 are also missed by the current literature. Occurring one year after the cattle show fog, these events might have been overshadowed by their immediate predecessor, but newspaper accounts suggest an anticyclone and a series of dense and persistent fogs extending over weeks.[11] Of the previously unidentified fog of 1882 (event 19), the *Times* (February 6, 1882, 7) wrote:

> By general consent the fog which prevailed over a great part of the metropolis during Saturday and Saturday night was one of the densest ever experienced. It was attended with all the usual inconvenience and incidents, intensified to an unprecedented degree. Trains were delayed, fog signals were heard in rapid succession on the railways, street lamps were lighted, street traffic was impeded and gradually suspended, many tramcars ceased to run, and businesses everywhere carried on by artificial light. In the streets, torches and lamps did not much expedite locomotion. Market carts failed to reach Covenant garden until many hours after they were due.

Last, it is important to point out that our procedure misses no fog-related event suggested by the existing secondary literature.

Figure 10.8 plots a measure of relative deviation, the residual death rate divided by the predicted rate, for event and nonevent weeks. Event week residuals are given by black triangles; nonevent week residuals by small, empty circles. The least severe events increased weekly death rates by 25 to 30 percent. The most severe events could double death rates, increasing them by 75 to 100 percent. To calculate the residuals, we estimate equation (1) using only nonevent weeks. The difference between the predicted and observed death rate equals the residual. The triangles are consonant with Brodie's data on the incidence of fog. The size of the residuals increase in the years leading up to 1891 and are more frequent before 1891 than after. There is a large and unusual spike in the nonevent week residuals in the eighth, ninth, tenth, and eleventh weeks of 1895. This is the result of an influenza epidemic (*Times,* March 9, 1895, 5). Note that the nonevent residuals fall below –.100 only twice, when they reach –.111 and –.103. To the extent that we expect symmetry in the structure of the error term, one might plausibly argue that any residual greater than .1 is generated by a different process than that which produces the nonevent residuals.

Figure 10.9 provides a look at the absolute effects of fog-related events. Plotting the excess number of deaths associated with event weeks, it shows increasing severity before 1891 and declining severity and frequency thereafter. The excess deaths associated with the fog-related events of the 1850s and 1860s numbered around 500, but by 1891, these deaths neared 2,000. It is significant that fog-related events cease after 1900. Taken together, the results in table 10.2 and in figures 10.8 and 10.9 support Brodie's conten-

11. On December 2, 1874, the *Times* quoted one observer as saying, "the most dense fog I ever saw in this locality." An editorial in the *Times* (January 8, 1875) attributed the large number of deaths in the metropolis to cold and variable temperatures, but this observation, combined with the numerous reports of dense fog over a long period, suggest an anticyclone.

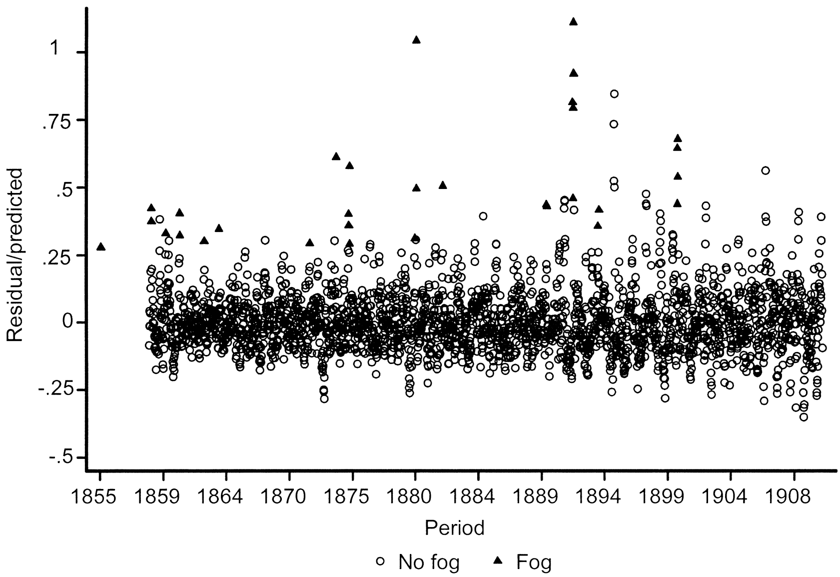

Fig. 10.8 Percentage deviation from predicted weekly crude death rate, 1855–1910
Source: See text.

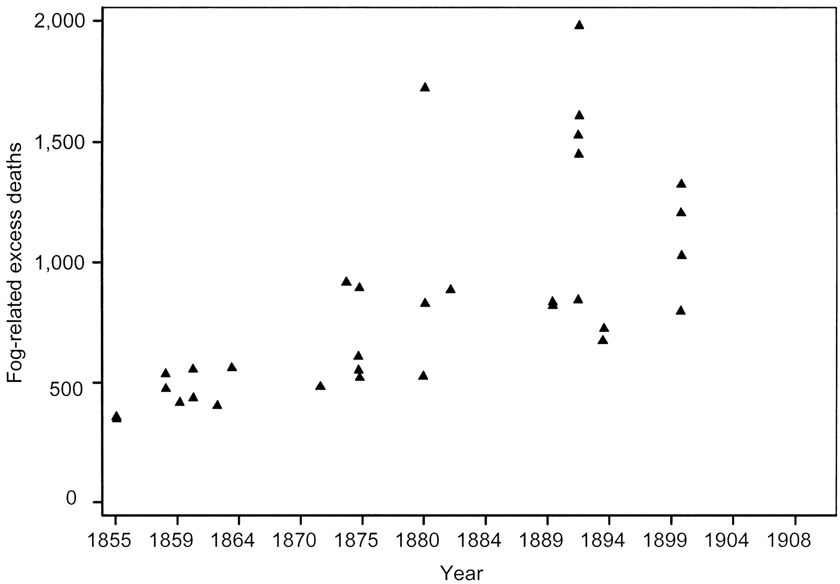

Fig. 10.9 Excess number of deaths during fog-related events
Source: See text.

tion that London's atmosphere was worsening before 1890 and improving thereafter.

One concern with the foregoing analysis is what demographers term "harvesting." In the case of fog-related events, suppose that fogs killed only the frailest and most sickly individuals, people who would have died within a few days or weeks of the fog, whether the fog had ever occurred. If so, the preceding data would overstate the significance of fog-related events. There is anecdotal evidence to support this hypothesis. Witness, for example, the coroner inquests of James Smith, Alice Wright, and William Henry Pepper, discussed previously.

To address this concern, we estimate the following variant of equation (1) using the full sample of event and nonevent weeks:

$$(2) \qquad d_{kt} = \alpha + w_k\beta_1 + y_t\beta_2 + \beta_3 N + \psi_0 F_0 + \psi_1 F_1 + \psi_2 F_2 + \ldots + \psi_{12} F_{12} + e_{kt},$$

where, F_0 is a dummy variable that assumes a value of one for all event weeks, and zero otherwise; F_1 is a dummy variable that assumes a value of one for the week immediately following an event week, and zero otherwise; F_2 is a dummy variable that assumes a value of one for two weeks after an event week, and zero otherwise; and so on down to F_{12}, which assumes a value of one for twelve weeks after an event week, and zero otherwise. All other variables in equation (2) have the same definitions as in equation (1).

Figure 10.10, which plots estimated coefficients on F_0 through F_{12}, suggests that deaths were not merely being rearranged. The black diamonds indicate a statistically significant coefficient at the 1 percent level; the empty circles indicate insignificant coefficients. The average fog-related event increased the weekly death rate by a statistically significant .16 points. In the first and second weeks after the event, the death rate remained a statistically significant .02 to .03 points above normal. Except for week four, all subsequent weeks are indistinguishably different from zero in terms of statistical significance. As for magnitudes, the point estimates are usually positive and are always very close to zero. Only weeks five, nine, and eleven fall below zero, to –.002, –.003, and –.007, respectively. These patterns are inconsistent with the hypothesis that fog-related events merely rearranged deaths, only causing people to die a few weeks or days earlier than they otherwise would have.

Equation (1) control for week and year fixed effects but not for rainfall and temperature. To the extent that fogs were associated with low temperatures, and low temperatures were associated with excess deaths, this estimating procedure imparts an upward bias to the effects of fogs. Although we have not been able to code and analyze the weather data that would allow us to expressly control for such concerns, we have located anecdotal evidence to suggest that, absent dense fogs, extremely low temperatures did not have

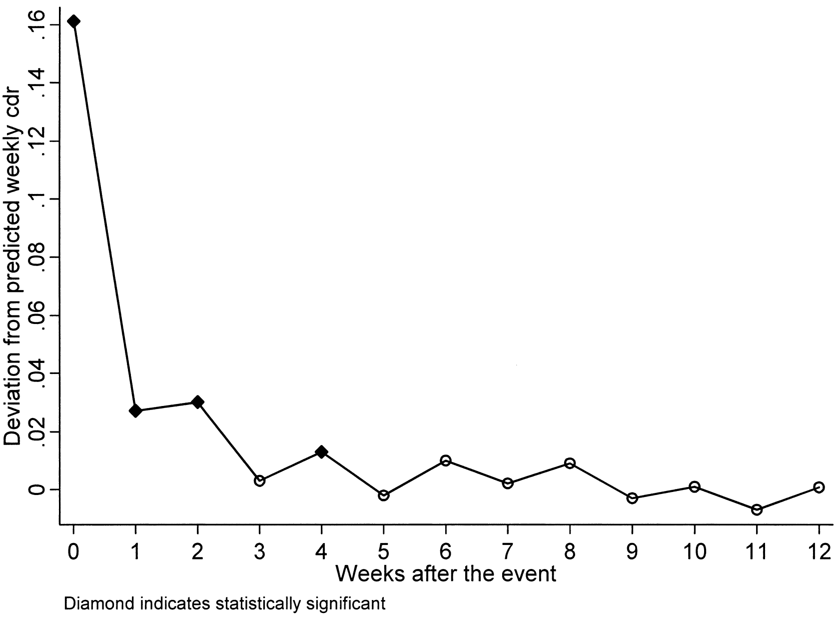

Fig. 10.10 Deviation from predicted death rate in weeks following fog-related events

Source: See text.

the same large effects on mortality.[12] Intense cold alone raised the death rate but not by the magnitudes we estimate for fogs and cold (*Times,* January 16, 1867, 6; December 14, 1897, 11; and February 4, 1879, 3). Also, for variation in temperatures to explain the inverted U-shaped pattern we find in fog-related events reported in figures 10.3 to 10.5, temperatures in England and London would have had to follow that same pattern. We have examined temperature data for the whole of Central England from a variety of sources (e.g., Manley 1974) and find little evidence of this.

Finally, in those cases where fog and cold struck London simultaneously, the fog was unique to London but the cold was not; the latter affected surrounding areas as well. If it had been the cold causing the excess deaths, the spike in death rates would have occurred for all areas with cold. But when we consult the *Weekly Reports of the Registrar General* and various accounts in the *Times,* both sources indicate that while the cold was a general event (affecting all cities and towns around London), the fogs and the spikes in mortality were not; they occurred only in London. Similarly, in his study of

12. It is our intention to use these data in subsequent research, but compiling the weather data and merging it the mortality data we use here is beyond the scope of this chapter.

the relationship between temperatures and the death rate in London, Dines (1894) argued that one should not be quick to attribute increased mortality during the winter quarter to reduced temperatures, but rather to increased crowding and a heavily polluted atmosphere.

Ideally, we would like to construct a panel of British cities, some of which were subject to smoke abatement efforts and some of which were not. With such a data set, we could perform a more formal and standard fixed effects estimation of the effects of smoke control on respiratory diseases. While we have identified a data source that would enable us to construct such a panel, we are unable at this stage compile and analyze the data. That is left for a later paper.

10.5 Concluding Remarks

We motivated this chapter with the simple question: did Frederick Brodie discover the world's first environmental Kuznets curve? The evidence presented in the chapter, though not conclusive, suggests that he did. The strongest single piece of evidence is the reverse event study, which shows that fog-related events—defined as unexplained spikes in weekly mortality rates—rose steadily in frequency and severity in the years leading up to 1891 and declined in frequency and severity thereafter. Furthermore, if one looks at sunshine measures, which in contrast to fog was measured instrumentally, there is evidence that sunshine rates in London were in decline relative to neighboring areas before 1891 and in ascension in the years following. In addition, qualitative evidence in the form of first-hand testimonials are presented throughout the paper to indicate that contemporary observers believed that London's atmosphere grew cleaner and more breathable in the wake of the Public Health Act. There is also some noisy evidence to suggest that annual bronchitis rates in London rose and fell with the incidence of fogs. Although we do not yet have the capacity to perform a full-blown analysis of panel data, evidence from other cities, particularly Glasgow, suggests that what was happening London was not unique: bronchitis rates grew increasingly frequent and severe with the rise of coal and subsided only with reductions in coal smoke.

There are at least three plausible mechanisms through which Londoners might have successfully curtailed their production of coal smoke, or at least dissipated the smoke. First, the preceding data indicate the population of Greater London redistributed itself, as central districts became less densely populated and outlying districts more so. If smoky fogs formed only when smoke density rose above a certain threshold, redistributing population might have reduced the number of fogs experienced by the metropolis as a whole. Second, with passage of the Public Health Act in 1891, businesses were fined for failing to consumer their own smoke, or otherwise generating excess amounts of smoke. In response, manufacturers switched from bituminous coal from Newcastle and elsewhere in England to Welsh steam coal, a harder coal that generated much less smoke, though it was about 20 percent more expensive than ordinary soft coal. Businesses also adopted more efficient stoking and firing procedures so that they economized on coal and minimized emissions of unburnt soot and tar. Third, the expansion of gas for cooking and heating helped undermine demand for coal among homeowners, who otherwise burned much of the coal in London.

If one were to plot real wages for unskilled laborers in London against foggy days per annum the typical EKC would emerge. At low levels of development, pollution (as proxied by fog) rose with real wages, but at some real-wage threshold, the correlation reversed itself and rising wages were associated with reductions in foggy days per year. It is difficult to say what the EKC means in this context. Perhaps it reflects an income effect, or perhaps the correlation between income and pollution is spurious, the result of a threshold effect for pollution. Ordinary citizens and voters tolerate pollution as long as it is below some level but begin actively lobbying for improvement once it crosses some threshold. The difficulty with the latter interpretation is that smoke abatements efforts in London had a long history, going back hundreds of years—though it was eventually repealed, the first statute prohibiting the burning of bituminous of coal in London was passed in 1273 (Martin 1906). It seems more likely that the metropolis had to reach some level income and technological advancement before it had the capacity to effectively deal with the coal smoke problem. This, however, is mere speculation. Fully resolving this question, and the other issues raised in the preceding, we leave for future research.

References

Ackerman, A. S. E. 1906. The distribution of producer gas as a means of alleviating the smoke nuisance. *Journal of the Royal Society for the Promotion of Health* 27:80–84.

Booth, W. H. 1898. Smoke Prevention. *Journal of the American Society of Naval Engineers* 10:1064–68.

Brazell, J. H. 1968. *London weather.* London: Her Majesty's Stationery Office.

Brimblecombe, P. T. 1987. *The big smoke: A history of air pollution in London since medieval times.* Cambridge, UK: Cambridge University Press.

Brodie, F. J. 1891. Some remarkable features in the winter of 1890–91. *Quarterly Journal of the Royal Meteorological Society* 17:155–67.

———. 1905. Decrease of fog in London during recent years. *Quarterly Journal of the Royal Meteorological Society* 31:15–28.

Caborne, W. F. 1906. Stoking and smoke abatement. *Journal of the Royal Sanitary Institute* 27:142–48.

Carpenter, A. 1880. Town smoke and town fog. *Westminster Review* 61:136–57.

Chandler, T. J. 1965. *The climate of London.* London: Hutchinson of London.

Dines, W. H. 1894. On the relation between the mean quarterly temperature and the death rate. *Quarterly Journal of the Royal Meteorological Society* 20:173–79.
Frankland, E. 1882. Climate in town and country. *Nature,* August 17.
Great Britain Board of Trade. 1903. *Report on wholesale and retail prices in the United Kingdom in 1902, with comparative statistical tables for a series of years.* Ordered by the House of Commons. London: Her Majesty's Stationery Office.
Hann, J. 1903. *Handbook of climatology. Part I. General climatology.* New York: MacMillan.
Lawther, P. J. 1959. Chronic bronchitis and air pollution. *Journal of the Royal Society for the Promotion of Health* 1:4–9.
Lempfert, R. G. K. 1912. Sunshine records: A comparison of sunshine statistics for urban and rural stations. In *Papers read at the smoke abatement conferences,* 23–28. Westminster, UK: Coal Smoke Abatement Society.
Livesey, G. 1906. Domestic smoke abatement. *Journal of the Royal Society for the Promotion of Health* 27:57–63.
Manley, G. 1974. Central England temperatures: Monthly means 1659 to 1973. *Quarterly Journal of the Royal Meteorological Society* 100:389–405.
Martin, A. J. 1906. Smoke prevention and coal conservation. *Journal of the Royal Society for the Promotion of Health* 27:85–107.
Mitchell, B. R. 1988. *British historical statistics.* London: Cambridge University Press.
Mossman, R. C. 1897. The non-instrumental meteorology of London, 1713–1896. *Quarterly Journal of the Royal Meteorological Society* 23:287–94.
Owens, J. S. 1912. Wasteful power production: With special reference with waste due to smoke. In *Papers read at the smoke abatement conferences,* 89–94. Westminster, UK: Coal Smoke Abatement Society.
Poore, G. V. 1893. Light, air, and fog. *Transactions of the Sanitary Institute* 14: 13–41.
Report from the Select Committee on Smoke Prevention. 1843. Great Britain. Parliament. House of Commons.
Report of the Smoke Abatement Committee. 1883. London.
Reynolds, M. 1882. *Stationary engine driving: A practical manual.* London: Crosby Lockwood.
Rideal, S. 1906. The abatement of smoke in factories. *Journal of the Royal Sanitary Institute* 27:149–51.
Russell, Rollo. 1906. The artificial production of persistent fog. *Journal of the Royal Sanitary Institute* 27:152–59.
———. 1912. Smoke and fog. In *Papers read at the smoke abatement conferences,* 21–22. Westminster, UK: Coal Smoke Abatement Society.
Russell, W. J. 1891. Town fogs and their effects. *Nature,* November 5.
Saward, F. E. 1899, 1908, and 1914. *The coal trade: A compendium of valuable information relative to coal production, prices, transportation, etc.* New York: The Coal Trade Journal.
Schaefer, T. W. 1907. The contamination of our cities with sulfur dioxide, the cause of respiratory disease. *Boston Medical and Surgical Journal* 157:106–10.
Schlicht, P. 1907. The production of coke and its application in domestic fires. *Journal of the Society of Arts* 684–98.
Scott, R. H. 1896. Notes on some of the differences between fogs, as related to the weather systems which accompany them. *Quarterly Journal of the Royal Meteorological Society* 22:41–65.
White, W. C., and P. Shuey. 1914. The influence of smoke on acute and chronic lung infections. In *Papers on the influence of smoke on health,* ed. O. Klotz and W. C.

White, 164–73. Pittsburgh: Mellon Institute of Industrial Research and School of Specific Industries.
Wise, W. 2001. *Killer smog: The world's worst air pollution disaster.* Lincoln, NE: iUniverse.com publication.
Wright, C. D. 1905. *Coal mine labor in Europe.* Washington, DC: GPO.