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: Information and the Impact of Climate and Weather on Mortality Rates During the Great Depression

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Chapter URL: http://www.nber.org/chapters/c11985

Chapter pages in book: (131 - 167)

5

Information and the Impact of Climate and Weather on Mortality Rates during the Great Depression

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Global warming has become a watchword for environmental policy over the past three decades. Daily temperature highs were thought to have reached the highest levels in recorded history within the past decade. Each month, there are reports of new studies of melting glaciers, thinning of ice caps on mountains, and warming in various areas throughout the world. Al Gore shared an Academy Award for his association with the movie *An Inconvenient Truth,* a film warning of global warming and its potential dire consequences. He then shared a Nobel Peace Prize with a group of scientists warning of the dangers of global warming. Much of the force of Gore's warnings about global warming comes from his predictions about the impact of warming on human populations and the economy. Yet the large volume of studies of climate change has not been matched by nearly as many studies of the impact of climate and weather on populations and economies or how populations and economies will respond. If the claims

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We would like to thank Hoyt Bleakley, Olivier Deschênes, Michael Greenstone, Sok Chul Hong, Shawn Kantor, Gary Libecap, Robert Margo, Rick Steckel, James Stock, participants at the National Bureau of Economic Research (NBER) Universities Conference on Climate Change in May 2008, and participants at the NBER Conference on Climate and History in May 2009 for their helpful comments.

that global temperatures will warm over the next few decades no matter what policy steps we take today are true, such studies are invaluable.

Here is a situation where history can serve as a guide to the impact of climate and weather on populations. We measure the impact of climate and weather fluctuations on infant mortality and noninfant mortality in United States counties throughout the Great Depression of the 1930s. The Great Depression was a period of great climate stress. It is arguably one of the two hottest decades in the 130 years in which the time-of-day adjusted temperature records have been readily available throughout the United States.[1] The heat created problems with droughts and Dust Bowls that contributed to the economic problems of the era as well as long-run responses to adapt to climate extremes.[2] Second, the Great Depression was a period of great economic vulnerability when climate might have had more impact on death rates. Unemployment rates were higher than 9 percent in every year between 1930 and 1940, over 14 percent in nine of those years, and exceeded 20 percent in the four years from 1932 through 1935. Annual real gross domestic product (GDP) in America was roughly 30 percent below its 1929 peak in both 1932 and 1933 and did not reach the 1929 level again until 1937.[3]

We have developed a database that combines information on infant and noninfant mortality rates, daily high temperatures and inches of precipitation, and a rich set of socioeconomic correlates for over 3,000 counties in the United States for each year between 1930 and 1940. We focus on infant mortality because infant mortality has long been seen as a key nonincome measure of standards of living, the death of an infant is an extraordinarily painful event, and infants are likely the most sensitive of populations to variations in conditions. We also examine the noninfant death rate to see if the patterns seen for infant deaths carry over to death rates for people in all age groups.

The results of the Great Depression analysis show the importance of controlling for access to information when measuring the relationship between mortality and climate. In analyses that do not control for measures of access to information, there is a strong positive relationship between mortality and temperature. When measures of illiteracy, access to radios, and access to magazines are incorporated in the analysis, the strong positive relationship

1. Steve McIntyre of www.climateaudit.org discovered an anomaly in the temperature data circa 1999 to 2000 that caused the National Aeronautics and Space Administration (NASA) to readjust its temperature rankings. In the United States, 1934 ranks slightly above 1998 as the hottest year on record. The years 1931, 1938, and 1939 also rank in the top ten. See http://www.climateaudit.org/?p=1880 and http://data.giss.nasa.gov/gistemp/graphs/Fig.D.txt.

2. See Hansen and Libecap (2003) and Cunfer (2005).

3. The 1930s also offer better data than earlier decades. It is the first decade in which infant mortality data were collected on a consistent basis for all states, and it is the first decade in which a large number of weather stations consistently reported daily information on high and low temperatures.

between mortality and temperature is no longer present. Researchers on the impact of climate, therefore, need to be mindful of the potential for such omitted variable bias when drawing conclusions about the impact of climate on various socioeconomic measures.

5.1 The Pathways between Climate, Weather, and Mortality

There is a long history of research linking climate to disease and mortality. Carl Spinzig (1880) developed an elaborate meteorological model designed to forecast yellow fever epidemics in American cities. Similarly, in his monumental *History of Epidemics in Britain,* Charles Creighton ([1894] 1965) argued that a wide range of diseases, including typhus, plague, pneumonia, influenza, and infantile diarrhea had seasonal or climatic components.[4] Leonard Rogers (1923, 1925, 1926) sought to forecast the likelihood of epidemics in India using climate variables. "Based on his conclusions, it was recommended that climatic variables be used for forecasting epidemics of TB, smallpox, and pneumonia and for mapping worldwide incidence of leprosy. However, such systems were never implemented on a wide scale" (World Health Organization [WHO] 2004, 12). More recently, Olivier Deschênes and Michael Greenstone (2007) have begun exploring the impact of fluctuations of weather on mortality.

In this chapter, we will focus on the influence on mortality of climate and weather fluctuations that can be effectively evaluated using county data during the Great Depression in America.[5] In discussing the role of climate and weather, the distinctions between the two are somewhat fluid. Climate is often defined by long-term weather patterns, while some people define weather as short-term deviations from the long-run patterns. A shift in climate occurs when what had been deviant weather patterns last for an extended period of time. When we translate these definitions for the empirical work in the chapter, the impact of climate will be analyzed when

4. Sadly, history often remembers Creighton for his ludicrous opposition to smallpox vaccination, but this in no way undermines the significance of his exhaustive and scholarly two volume history.

5. Weather extremes that damage crops can generate increases in food prices that can lead to famine in autarkic and subsistence economies. We do not focus on that mechanism much in this chapter because we are using county-level data in the United States in a period where the markets extended beyond county boundaries and often beyond state and national boundaries. Thus, the effect of local weather on food prices was not as strong. For further evidence on this issue, see Fox, Fishback, and Rhode (chapter 4 in this volume) on the impact of weather fluctuations on state-level prices of corn and hay. In more-developed economies, increased food prices can induce consumers to switch to cheaper, low-quality foods. The "antebellum puzzle" prior to 1860 offers a prime example. Despite rising per capita incomes, mortality rates rose and access to nutrition declined as increases in food prices, especially for meat, encouraged American consumers to switch away from high-protein meat products to lower quality foods. See Komlos (1987); Haines, Craig, and Weiss (2003); and Steckel (1992). As another example, Galloway (1985) used annual data for London from 1670 to 1830 to show how bad weather and poor harvests conspired to raise both agricultural prices and mortality.

both cross-sectional and time series variation are used as the sources of identification of the relationship between temperature and precipitation and mortality. Weather fluctuations will be addressed when the analysis shifts to the use of differencing to control for time-invariant features of the counties and, thus, the source of identification is variation across time in the same county. The two key components of climate and weather examined in the analysis are temperature and precipitation.

5.1.1 Temperature

There are a variety of ways in which temperature and precipitation might influence mortality. The most obvious relate to exposures to extreme heat or cold. For example, New York City was struck by an intense heat wave in August 1896. The *New York Times* reported that the severe heat led to 500 early deaths and many more instances of heat prostration. Out-of-town newspapers put the numbers afflicted in New York City even higher. Due to the oppressive temperatures, many of the city's working horses dropped dead in the street; in the age before automobiles, the carcasses could not be moved without putting other horses at risk.[6] Local charities and governments responded to such extreme temperature events by providing relief in various forms (free ice, fuel, or access to protected space). And indeed, during the Great Depression period under study, record cold temperatures in the winter of 1933 to 1934 induced New Deal authorities to extend work relief programs that were set to terminate.

Fluctuations in temperature were identified by public health officials as contributors to mortality in many other ways during the nineteenth and early twentieth century. These officials argued that infant mortality spiked upward during July, August, and September because the warm weather was conducive to the proliferation and spread of bacteria in milk and water. Milk samples in Washington, DC in the summers of 1906 and 1907, for example, contained average counts of 11 to 22 million bacteria per cubic centimeter, two to four times the level found in sewage from major American and European cities at the time (Rosenau 1909). Such food or waterborne pathogens were considered to be likely suspects because most infant deaths during the summer were from diarrheal diseases, and there was no summer spike in mortality for infants who were breastfed and, therefore, not exposed to bacteria in water and cow's milk.[7]

Water-related diseases compounded the problem of milk-related diar-

6. See *New York Times* (6 August 1896, 1; 7 August 1896, 5; 8 August 1896, 5; 9 August 1896, 1; 10 August 1896, 1; 11 August 1896, 1–2; 12 August 1896, 1; 13 August 1896, 4; 16 August 1896, 8); *Chicago Tribune* (13 August 1896, 5; 14 August 1896, 4; 15 August 1896, 1); *Washington Post* (9 August 1896, 1; 12 August 1896, 1); and *Los Angeles Times* (12 August 1896, 3).

7. The literature on the summertime spike in infant mortality is voluminous. For a few representative examples, see Phelps (1910); Eghian (1905); *Lancet* (November 15, 1884, 882); Sedgwick and MacNutt (1910); and Routh (1879, 35–42). On the viability of bacteria in warm milk, see *Science* (August 16, 1889, 116–18).

rheal infections because parents and vendors often used water to dilute the milk. Typhoid, the most serious waterborne disease in the United States at the turn of the century, also peaked during the late summer and early fall, although the mechanisms that drove this spike are far from clear (Whipple 1908, 123–27). Surprisingly, experiments from this era repeatedly showed that typhoid bacteria in water were more common and more vital during the winter months than the summer. Direct sunlight, more common in the summer, also inhibited the growth of waterborne bacteria (*Journal of the American Medical Association,* March 16, 1895, 415). Given the relative vitality of typhoid bacteria during colder months, we can only speculate that typhoid peaked during the summer because people drank more water in the summer heat or because there was some unidentified interaction between tainted water and the broader environment.

The warm, more tropical weather of summer led to rapid multiplication of the number of insects, which represent another possible vector through which climate change could affect disease rates and overall mortality. The summer proliferation of flies creates a serious public health risk whenever populations used privies and cesspools to dispose of human waste. The flies interacted with excreta and waste and then contributed to the spread of pathogens associated with typhoid fever and other diarrheal diseases. The pervasiveness of flies led public health officials to emphasize the importance of public sewer systems and well-screened privies in forestalling the transmission of typhoid and diarrhea (Whipple 1908, 123–27; Bergey 1907; Hewitt 1912). While not so relevant for the United States, tsetse flies are also carriers of sleeping sickness in central Africa (Hewitt 1912).

Mosquitoes, too, might have been important carriers of disease in early twentieth century America. Although yellow fever, malaria, dengue, and other mosquito-related illnesses were not as common in the United States as they were in Africa and parts of Asia, the available data suggest malaria was not uncommon in the American South and represented a serious public health threat during the nineteenth and early twentieth centuries (Herrick 1903; Humphreys 2003). In Mississippi, malaria was the seventh-leading cause of death in the state in 1900. In a handful of cities such as Paducah (Kentucky), Jacksonville (Florida), Savannah (Georgia), and Wilmington (North Carolina), the death rate from malaria was between 100 and 200 deaths per 100,000 persons, rivaling the death rates from pneumonia, influenza, and typhoid fever (U.S. Bureau of the Census 1908, 34–35). Studying the early twentieth-century United States, Brazil, Colombia, and Mexico, Bleakley (2007) shows that mosquito eradication raised labor productivity significantly.[8]

8. There is evidence to suggest that the extent of malaria in the United States during this period was overestimated. Malaria cases were frequently misdiagnosed cases of typhoid fever, particularly among African Americans. Typhoid and malaria shared common symptoms and

Even as typhoid, diarrheal diseases, and insect-borne diseases spiked during the summer months, respiratory diseases spiked during the winter months. Pneumonia, influenza, tuberculosis, bronchitis, and, to a lesser extent, diphtheria, all rose sharply when the temperature fell (Clemow 1903, 14–21). The connection between cold temperatures and respiratory diseases was well-documented and understood before the development of the germ theory of disease. In 1864, the Massachusetts Board of Health and Birth and Death Registry (1866, 59) gave examples of the well-known pattern of winter peaks in deaths from pneumonia: "The greatest number of deaths (281) was in March, and the least (42) in August. More than half of the deaths (53.8) occurred during the first four months [of the year], and only 15.33 per cent from June to October, inclusive; showing the well development of this disease in the cold season." Similarly, monthly data from the City of Chicago between 1871 and 1906 in figure 5.1 show a strong negative relationship between the monthly temperature and the pneumonia death rate.[9]

There are at least three reasons to expect respiratory diseases to be more common during the winter months. Historical observers emphasized that cold weather caused people to spend more time indoors, where respiratory diseases were more easily spread in crowded and poorly ventilated homes. Some bacteria and viruses grow and reproduce more rapidly in cooler temperatures than in warm ones or simply find cooler temperatures more amenable.[10] Viruses, for example, become more stable at lower temperatures (Zinsser et al. 1980, 157). Respiratory viruses are also inhibited by summer heat and solar radiation, and recent work suggests that in temperate climates viral activity is greatest during the winter months (Yusuf et al. 2007; Sagripanti and Lytle 2007). Moreover, environmental forces such as cold weather and humidity are more important than factors such as population density and migration in the propagation of the influenza virus (Alsono et al. 2007;

were routinely conflated by physicians under the misleading name "typho-malaria" fever. In compiling mortality statistics for the country during the early 1900s, the United States Census Bureau (1908, 34–35) wrote: "Death rates from malarial fever are usually of little importance, and may be subject to possible correction for inclusion of deaths actually due to typhoid fever, a disease which is frequently confused in the returns with malarial fever." Most telling, when American cities began filtering water supplies—which should have affected typhoid rates but not malaria because filtering water did not kill mosquitoes—malaria rates fell sharply (Troesken 2004, 170–78). The upshot of this discussion is that high temperatures and excessive rainfall might affect malaria rates in the United States, but given the questionable prevalence, malaria might not prove to be an important source of variation in overall death rates.

9. The plot reveals a strong statistical correlation with an R^2 of 0.32 for the regression line in the chart with a coefficient on temperature of –0.23, which is statistically significant at the .0001 level.

10. For microbial activity in general, the available evidence suggests most microbes become less active or dormant during the winter months. See Jones and Cookson (1983). This, however, does not rule out the possibility that some subset of microbes become more active during the winter. Recent research, for example, indicates that listeria can reproduce and multiply even at low temperature levels (Chan and Weidmann 2009).

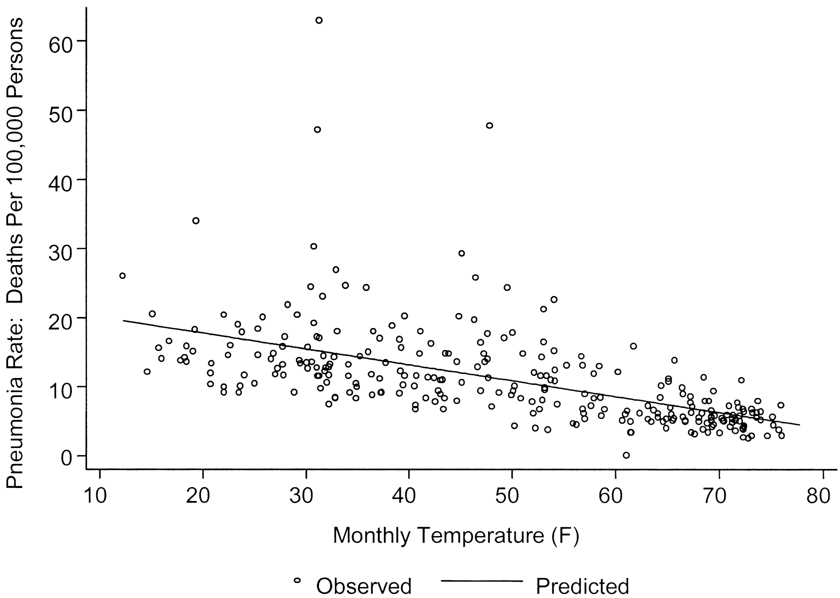

Fig. 5.1 Pneumonia deaths per 100,000 people plotted against monthly temperature, city of Chicago, 1871–1906

Source: City of Chicago (various years between 1871 and 1906).

Reichert et al. 2004). Finally, during the winter months, people were exposed to more pollution. Before the widespread adoption of gas heating, emissions from coal, oil, fires, and stoves rose in winter as people heated their homes.

In analyzing the long-run time series relationships between temperature and mortality within the year, it is important to identify whether the relationship is determined by the long-term month-to-month variation in temperature across the year or fluctuations in temperature around the long-term norms. To illustrate the differences in effects, we use ordinary least squares (OLS) to estimate the relationship between the pneumonia death rate and temperature in the data for Chicago from 1871 to 1906 in figure 5.1. In the analysis, we control for the long-term trend using a year counter and perform the estimation without and with month fixed effects. Without month fixed effects, the results in table 5.1 show a very strong and positive relationship between temperature and pneumonia death rates, as an additional degree Fahrenheit of temperature was associated with an additional pneumonia 0.687 deaths per 100,000 people. This relationship might have been driven by long-run relationships between temperatures across months of the year—July is much hotter than January, for example—or by fluctuations in temperature around the typical temperatures seen at particular times of year.

In the second regression in table 5.1, we include month fixed effects to

Table 5.1 **Ordinary least squares regression results with and without month fixed effects for monthly data on pneumonia deaths per 100,000 people as a function of temperature in Chicago, 1871–1906**

	Coefficient (*t*-statistics)	
Constant	2,435.9	2,461.8
	(12.16)	(16.12)
Temperature	0.687	0.079
	(11.14)	(0.47)
Year trend	–1.283	–1.284
	(–12.10)	(–15.89)
Month fixed effects		
February		–1.740
		(–0.42)
March		2.650
		(0.59)
April		0.582
		(0.10)
May		–3.898
		(–0.56)
June		0.228
		(0.03)
July		55.670
		(6.11)
August		33.401
		(3.72)
September		6.395
		(0.80)
October		–7.991
		(–1.24)
November		–11.860
		(–2.44)
December		–5.388
		(–1.27)
No. of observations	432	432
R^2	0.387	0.653

Source: Data collected from the city of Chicago (various years between 1871 and 1906).
Note: For tables 5.1 through 5.6, coefficients with *t*-statistics listed in parentheses.

control for long-run differences across months that do not vary from year to year. The results show that time-invariant features of the month of July were associated with spikes of 55.67 in the number of pneumonia deaths per 100 thousand people, relative to January. The spike for August was 33.4 and death rates were 11.86 lower in November than in January. After controlling for these time-invariant features of each month, the relationship between pneumonia deaths and temperature was cut sharply from 0.687 to 0.079 and is no longer statistically significant. This second set of results suggest that the long-run unchanging differences in conditions between July, August, and

November are the key factors influencing differences in pneumonia death rates over the course of the year. The long-run differences might well be related to the long-run core differences in temperature between each month. If this is the case, the much lower impact of temperature in the regression with month fixed effects shows that fluctuations in temperature around the long-run core temperatures in a month have only a weak influence on the pneumonia death rate. This finding foreshadows one of the findings when we examine the county panel data for the entire United States. It appears that long-run differences in temperature conditions across the country influence mortality rates. After we control for those long-run conditions, however, short-term fluctuations in weather around those long-run differences have much smaller impact.

5.1.2 Rainfall

Rainfall and the resulting pools of water that stimulate the breeding of mosquitoes have also been found to be contributors to disease and mortality although the impact varies by type of disease. Rogers's original studies of rainfall data in the Northwest Provinces of India indicated that smallpox epidemics were unheard of during periods of heavy rainfall, erupting instead when rain was limited. Nishiura and Kashiwagi (2009) have reproduced Rogers's findings using modern econometric and epidemiological techniques, while MacCallum and McDonald (1957) found evidence that humidity and warm temperatures undermine the viability and lifespan of the smallpox virus.

Although vaccination programs launched by American states during the nineteenth century had mostly (though not entirely) eliminated smallpox by the 1930s, it is not difficult to postulate other mechanisms linking rainfall to disease and mortality. For example, sewage-tainted water was a common transmission vector of both diarrheal disease and typhoid fever. To the extent excessive rainfall diluted the sewage found in public water sources, it would have also reduced the amount of waterborne illness. Consistent with this line of thought, serious flooding in the rivers around Pittsburgh (from which the city drew its water) during the mid-1890s was associated with unusually large drops in the city's diarrhea and typhoid rates (Troesken 2004, 29, 56). This connection, though speculative, might help explain some findings reported later in the chapter that suggest an inverse correlation between rainfall and infant mortality.

5.2 Mortality, Weather, Information, and Economic Development

The relationships between climate, weather, and mortality are highly specific to context, and they are mediated through institutions and technologies developed by humans. As people understood more about the mechanisms that connected climate to disease, they developed means of prevention that served to reduce the measured impact of climate. To illustrate, during the late nineteenth century, scientists began to understand that the rise in diarrheal deaths during the hot summer months was related to pathogens that thrived in unpasteurized milk and unfiltered water supplies. Methods for pasteurization and water purification were developed to destroy nearly all of the pathogens that cause typhoid and diarrhea. As pasteurized milk became more common and cities filtered public water supplies, the rates of typhoid and diarrhea no longer varied much by season or in response to temperature. Similarly, flies were much less likely to spread disease once cities replaced outdoor cesspools and privies with public sewer systems and indoor toilets.

Similar improvements in mortality were seen in smaller cities and rural areas even though they were slower to adopt sewer systems and filtered water. The lower population densities allowed such areas to have lower mortality in the late 1800s by alleviating problems, like the spread of infectious disease, associated with tightly packed populations. Even though smaller cities and rural areas were slower to adopt sewers and filtered water, people were able to limit the impact of flies by using more screens and introducing concrete vault privies with chemical treatments that limited the impact of the privies on local water supplies and the fly problem (Fishback and Lauszus 1989). To the extent that vaccinations minimized the propagation and spread of influenza, the winter spike in mortality tended to moderate.

The influence of public health education and prevention on the relationship between temperature and infant mortality is illustrated in figure 5.2, which plots the infant mortality rate in Chicago against temperature using monthly data for two periods, 1871 to 1890 and 1895 to 1907. Smoothed lines that capture the typical relationships between temperature and infant mortality rates for the two periods are included to make the typical differences easier to see. The black triangles representing months between 1871 and 1890 show a flat relationship between average monthly temperature and infant mortality for temperatures between 15° and 60°F. After reaching 65°, however, the infant mortality rate leaps in response to higher temperatures, rising from less than 50 deaths per 100,000 (per month) to 100 to 250 deaths. This leap illustrates why nineteenth-century observers were so concerned about disease during the summer. Between 1890 and 1895, Chicago introduced water purification, mandated tougher milk inspection, and the diphtheria antitoxin was introduced. What happened? The 1895 to 1907 observations marked by empty circles are typically 50 percent lower than the triangles for 1871 to 1890. It is even more remarkable that the strong correlation between high temperatures and infant mortality above 65° is essentially eliminated (Ferrie and Troesken 2008). To the extent that the cities and urban areas contained in our Depression-Era sample had made similar investments, we do not expect to observe strong correlations between infant mortality (or mortality in general) and temperature and rainfall.

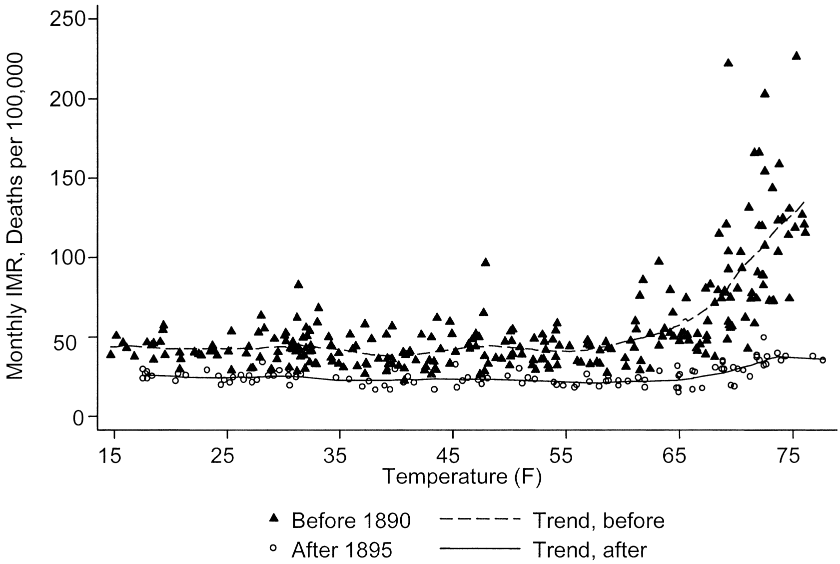

Fig. 5.2 Relationships between infant deaths per 100,000 people and the monthly average of time-of-day adjusted temperature in Chicago, 1855–1890 (triangles) and 1895–1906 (dots)

Source: City of Chicago (various years between 1871 and 1906).

The introduction of these new public health technologies reduced the measured relationship between climate, weather, and mortality, but not everybody gained access to the information or the technologies. In the 1910s and 1930s, public health officials at all levels developed education programs to teach people simple ways to reduce the spread of disease with emphasis on washing hands and food and making sure that pools of water did not form in mosquito season (Fox 2009). The illiterate and people with limited access to information were less likely than the rest of the population to receive these messages. If there were enough of the ill-informed who drank unpasteurized milk or unfiltered water or did not adequately deal with privies, the long-run climate and mortality relationships still would have continued. The success of public health programs at eliminating such interactions is, therefore, an empirical question that we begin to address in the next section.

5.3 Data and Estimation

To examine the impact of climate/weather on death rates during the 1930s, a series of OLS regressions are estimated with White-corrected robust standard errors clustered at the state level. The regressions take the basic form

$$DR_{it} = \beta_0 + \beta_1 W_{it} + \beta_2 X_{it} + \varepsilon_{it},$$

where DR is the death rate in county *i* in year *t*. We estimate separate regressions for infant mortality rates; the number of infant deaths per 1,000 live births; and, for the noninfant death rate, the number of deaths of people over the age of one per 1,000 people. W_{it} is a vector of climate/weather variables in county *i* in year *t*. We use several different measures of weather that either focus on annual averages of rainfall and temperature or on distributions of the number of days at different temperatures over the course of the year. The X_{it} vector refers to a wide range of correlates that include demographic, economic, New Deal spending, and geographic variables describing county *i* in year *t*. Appendix table 5A.1 contains a list of the correlates with information on means and standard deviations for the panel.

The data set for estimation is annual data for 3,054 counties (or groupings of counties designed to match up with New Deal spending information) each year for the years 1930 through 1940. The data on daily high temperatures and precipitation are aggregated from information originally collected by the United States Historical Climatology Network from 362 weather stations that were operational by 1930 and had complete daily weather data between 1930 and 1960. To measure the daily weather at each county seat, we used the Haversine formula to convert information on latitude and longitude from two locations to measure the distances between weather stations and county seats. The daily weather at the nearest weather station was used as a proxy for the weather in the county.

The information on infant deaths, noninfant deaths, and births used to construct death rates and are from annual volumes of *Birth, Stillbirth and Infant Mortality Statistics for the Continental United States* and *Mortality Statistics* (U.S. Bureau of the Census, various years). The sources for the correlates are in the appendix.

We start with an analysis of the role of climate/weather on infant mortality that takes into account both cross-sectional and time series variation. In the following, we discuss the impact of weather changes when we incorporate geographic fixed effects to control for long-term climate. The initial analysis starts with an OLS regression of infant mortality as a simple linear function of annual average high temperature and annual precipitation. Table 5.2 shows a series of OLS regressions with and without correlates. In the sparest specification (1), the number of infant deaths rises by a statistically significant 0.72 per 1000 live births with an increase of 1°F in annual average temperature. Meanwhile, greater precipitation has a small and imprecisely estimated negative effect on infant mortality of –0.12 deaths per life birth for a one-inch increase in annual precipitation.

The most interesting feature of table 5.2 is what happens to the impact of temperature as correlates are added to the analysis. The sizeable effect of temperature on infant mortality largely goes away when we add one correlate to the analysis, the percentage illiterate. Just the addition of that one variable cuts the effect of high temperature from 0.72 in specification (1) to a statistically insignificant 0.095 in specification (2). Meanwhile, the percent

Table 5.2 **Coefficients and *t*-statistics from regressions of infant deaths per thousand live births on annual average high temperature, annual precipitation, and other correlates**

	Coefficient (*t*-statistics)				
Variable	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
Average daily high temperature in year	0.722 (6.18)	0.095 (1.04)	–0.062 (–0.62)	0.427 (1.92)	–0.183 (–1.58)
Inches of precipitation during year	–0.121 (–1.36)	–0.288 (–3.48)	–0.276 (–3.32)	–0.108 (–1.91)	–0.160 (–3.7)
% illiterate		2.049 (5.91)	1.867 (5.17)		2.069 (3.99)
% owning radio			–0.261 (–6.13)		–0.413 (–10.56)
Per capita circulation of 15 magazines, 1929			0.348 (4.52)		–0.220 (–2.96)
Remaining correlates included				Included	Included
N	32,598	32,598	32,584	32,423	32,421

Notes: The regressions have White-corrected robust standard errors, which are clustered at the state level. Reported R^2 range from 0.039 to 0.22. The remaining correlates are retail sales per capita; auto registrations per capita; tax returns filed per capita; crop value, percent home ownership; Public Works Administration grants per capita; Agricultural Adjustment Administration grants per capita; relief grants per capita; Public Roads Administration grants per capita; Disaster Loan Corporation, loans per capita; farm loans per capita; Reconstruction Finance Corporation loans per capita; U.S. Housing Authority loans per capita; Civilian Conservation Corps camps established in year t; Civilian Conservation Corps camps established in year $t-1$; Civilian Conservation Corps camps established in year $t-2$; hospital beds per female aged fifteen to forty-four potentially available for infants, employment in polluting industries, 1930; coal tonnage, results of bovine tuberculosis testing; births per woman aged fifteen to forty-four; percent women aged twenty to twenty-four of women aged fifteen to forty-four; percent women aged twenty-five to twenty-nine of women aged fifteen to forty-four; percent women aged thirty to thirty-four of women aged fifteen to forty-four; percent women aged thirty-five to forty-four of women aged fifteen to forty-four; percent urban; percent foreign-born, percent African American; population per square mile; percent families with electricity; manufacturing employment per capita; retail employment per capita; number of lakes; number of swamps; maximum elevation; elevation range; percent church membership; number of rivers that pass through eleven to twenty counties in county; number of rivers that pass through twenty-one to fifty counties in county; number of rivers that pass through over fifty counties in county; number of bays; number of beaches, on Atlantic Coast, on Pacific Coast, on Gulf Coast, on Great Lakes; land area in square miles, and a constant term.

illiterate in the population has a strong and statistically significant impact of raising the infant mortality rate by two deaths per thousand for a 1 percent increase.

The importance of knowledge is reinforced by the addition of two more measures of access to information to the analysis, the share of households with radios, and the per capita circulation of fifteen news magazines in 1929. When both are added to the analysis, the coefficient of temperature falls from 0.09 in specification (2) to –0.06 in specification (3). While the presence of the radio is associated with reductions in infant mortality, the impact of the magazine circulation variable is unexpectedly positive. However, there appears to be a positive omitted variable bias to this coefficient because when a full set of income, demographic, and geographic correlates is added to the analysis, the coefficient has the expected negative effect.

It is dicey to argue for the importance of a small number of variables by adding them to the analysis without the other correlates because of cross-correlations between correlates. In this case, however, the importance of the information variables stands out when all of the other correlates are included. Specification (4) of table 5.2 shows the climate coefficients when all of the correlates except for the information variables are included in the analysis. The inclusion of the other correlates as a group cuts the impact of the average high temperature in half from 0.72 to 0.427. When the information variables are added to the rest of the correlates in specification (5), the temperature coefficient is cut dramatically from 0.427 to –0.183. In this specification, the coefficients of the information variables are all statistically significant with the expected signs: infant mortality is positively related with illiteracy, less access to radios, and less readership of magazines.

This sequence of results shows the importance of incorporating access to knowledge in studies of the relationship between climate and mortality. Had the measures not been included, we would have concluded that high temperatures were strongly related with higher infant mortality. In fact, once measures of access to knowledge were included, the results show that the real culprit that contributed to higher infant mortality was less access to knowledge, and people with less access to knowledge were much more likely to live in areas with higher temperatures, on average.

There are a huge number of potential specifications for the temperature and precipitation variables that could be tried. We explored a number of higher-order polynomial specifications with squared and cubed terms. However, there is relatively little gain to this with the annual average data primarily because average annual temperatures only ranged from 47° to 91°F in the sample. Given the small range and the relative inflexibility of the polynomials, other approaches are preferred.

We estimated a model with a relatively flexible formulation for temperature by using the share of days of the year that the daily high temperature was in different temperature bands. Table 5.3 shows the relationships between infant mortality and climate with and without the information variables and the remaining correlates. Because the shares of the temperature bands sum to one, we excluded a reference temperature band for days with daily highs at or above 50° and below 60°. The simplest specification is somewhat surprising. We anticipated that more days above 100° would lead to higher infant mortality. The coefficient was a positive 2.4, but the effect was not statistically significant. Relative to the 50 to 60° range, higher infant mortality was associated with a higher share of days with temperatures in the 70s and less than zero. Greater precipitation was also associated with lower infant mortality.

Table 5.3 **Coefficients and *t*-statistics from regressions of infant mortality rate on share of days during year in temperature bands, annual precipitation, and other correlates**

	Coefficient (*t*-statistics)				
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
Share of days in year that high temperature					
High ≥ 100	2.380	13.166	23.970	38.723	23.875
	(0.06)	(0.44)	(0.81)	(1.17)	(0.99)
100 > high ≥ 90	2.365	–45.003	–39.928	–19.275	–26.444
	(0.11)	(–2.53)	(–2.11)	(–0.78)	(–1.78)
90 > high ≥ 80	24.540	–11.216	–0.878	9.674	0.692
	(1.18)	(–0.72)	(–0.07)	(0.56)	(0.06)
80 > high ≥ 70	61.178	1.87115	–4.687	18.363	–1.651
	(2.62)	(0.12)	(–0.32)	(1.02)	(–0.15)
70 > high ≥ 60	12.142	–30.066	–22.320	7.312	–2.311
	(0.5)	(–1.81)	(–1.61)	(0.47)	(–0.18)
60 > high ≥ 50	—	—	—	—	—
50 > high ≥ 40	1.206	8.824	18.793	5.300	27.597
	(0.05)	(0.5)	(1.26)	(0.34)	(2.3)
40 > high ≥ 30	–60.914	–48.932	–31.442	–40.911	–16.862
	(–2.23)	(–2.33)	(–1.68)	(–2.19)	(–1.18)
30 > high ≥ 20	–4.604	–23.524	–3.196	–20.393	–4.084
	(–0.15)	(–0.98)	(–0.14)	(–1.06)	(–0.25)
20 > high ≥ 10	–89.439	–97.978	–64.273	–47.681	5.786
	(–2.26)	(–3.31)	(–2.63)	(–1.8)	(0.23)
10 > high > 0	–57.800	–56.908	–33.339	–116.910	–8.869
	(–1.1)	(–1.42)	(–0.87)	(–2.13)	(–0.23)
0 > high ≥ –10	131.196	42.228	32.505	12.780	45.641
	(1.72)	(0.61)	(0.48)	(0.21)	(0.63)
–10 > high	184.886	41.908	49.850	130.359	135.520
	(1.39)	(0.42)	(0.62)	(1.29)	(1.3)
Inches of precipitation during year	–0.209	–0.307	–0.281	–0.146	–0.155
	(–1.95)	(–3.39)	(–3.03)	(–2.36)	(–3.3)
% illiterate		2.147	1.965		2.065
		(6.24)	(5.51)		(3.92)
% owning radio			–0.252		–0.408
			(–6.55)		(–10.45)
Per capita circulation of 15 magazines, 1929			0.310		–0.220
			(3.72)		(–2.97)
Remaining correlates included				Included	Included
N	32,598	32,598	32,584	32,423	32,421

Note: See table 5.2 notes.

Dash indicates reference temperature band.

The effects of climate/weather are transformed once again when we include additional correlates, but the story is not as simple as the one told in the preceding. The inclusion of all but the information variables in specification (4) in table 5.3 leads to a sharp rise in the effect of shares of days over 100° from 2.4 to 38.7, such that a 1 percent increase in the share raises the infant mortality rate by 0.387, but the effect is statistically insignificant. Many of the effects in the spare specification (1) are weakened sharply. Adding the information variables in specification (5) cuts the impact of days over 100° roughly in half to 23.9, while leading to a statistically significant effect of the share of days with temperatures in the 40s. In general, most of the temperature bands do not have much effect on infant mortality rates.

5.4 Infant Mortality and Annual Fluctuations in Temperature and Precipitation

The prior section focused on the impact on infant mortality of climate because so much of the variation in the analysis was cross-sectional across counties. In this section, we perform a difference analysis that controls for time-invariant features of each county and for common shocks to infant mortality throughout the country that occurred in specific years. The equation estimated takes the following form:

$$\mathrm{DR}_{it} - \mathrm{DR}_{it-1} = \alpha_0 + \alpha_1 (W_{it} - W_{it-1}) + \alpha_2 (X_{it} - X_{it-1}) + \alpha t + \varepsilon_{it} - \varepsilon_{it-1}.$$

where $(\mathrm{DR}_{it} - \mathrm{DR}_{it-1})$ is the change in the mortality rate (infant or noninfant) infant mortality from the previous year, $(W_{it} - W_{it-1})$ is a vector of changes in weather from the previous year, $(X_{it} - X_{it-1})$ is a vector of changes in other correlates from year to year, t is a vector of year dummies, and $(\varepsilon_{it} - \varepsilon_{it-1})$ is the change in unobservable factors that vary across time.

By estimating the relationship between the change in infant mortality and the change in weather, the analysis controls for factors that vary across counties but did not change over time. To the extent that the climate in the area is considered time-invariant, the analysis controls for the climate, and the vector of α_1 coefficients captures the relationship between changes from year to year in the weather and changes in infant mortality. An alternative description is that the analysis captures the effects of weather deviations from the long-run climate on infant mortality. The differencing also controls for time-invariant features of the geography. The inclusion of a vector of year dummies controls for factors like the introduction of sulfa drugs in 1936 and 1937 that would have affected all of the counties simultaneously (Thomasson and Treber 2008).

A number of the variables that we included as controls in the prior section were based on census information reported only in 1930 and 1940. As seen in the data descriptions in appendix table 5A.1, we used straight-line interpolations between the census years to fill in values for these variables in the intervening years. So the values in the prior section were basically trend values for those variables. Because the change in these variables would be the same in each year, we do not include them in the differencing specification. The variables that we do include in the $(X_{it} - X_{it-1})$ correlates vector either vary from year to year (share of tax returns, hospital beds per capita, measures of bovine tuberculosis, the general fertility rate [births/interpolated value for share of women aged fifteen to forty-four]), or we could use changes in state measures to interpolate between various years throughout the period (retail sales per capita, auto registrations per capita, crop values per farm population, the New Deal program measures.)

Specifications (I-1) and (I-2) in table 5.4 show the results of the difference analysis using the simplest form of the changes in average annual high temperatures and changes in annual inches of precipitation, while specifications (I-3) and (I-4) show the results using changes in the share of days in different temperature bands. The simple specifications of annual averages in specifications (I-1) and (I-2) suggest that weather fluctuations had little or no effect on infant mortality rates. The coefficients on both precipitation and average daily highs are small and statistically insignificant in specifications both with and without the extra correlates. The coefficients of the changes in the shares of days within each temperature band in specification (I-4) suggest a similar story. There are only two coefficients of the change in the percentage days in each temperature band that are statistically significant at the 10 percent level or better, the ones for temperatures in the thirties and temperatures in the teens. The effects are small, however, with elasticities for all coefficients below –0.06, such that a 1 percent rise in the share of days in the temperature band would have led to at most a –0.06 percent reduction in infant mortality.

The analysis in table 5.4 also includes information on the coefficients of the other time-varying correlates in the analysis. A number of the relationships with infant mortality have been seen in other studies of death rates, in some cases including infant mortality rates. As seen here, a number of studies show a positive relationship between death rates and the number of hospital beds in an area. There are several potential reasons for this effect. One is that the data on deaths report the location of the death not the residence of the deceased. Areas with more hospital beds tend to report more deaths because people with potentially fatal illnesses from areas without hospitals often came to areas with hospitals to receive treatment. A second possibility is that there was endogeneity bias because areas with higher death rates were more likely to add more hospital beds per capita. Because increased numbers of hospital beds involved capital expenditures, this effect may have been weakened to the extent that the addition of hospital beds lagged a rise in the death rate by a year or two.

Table 5.4 **Coefficients and *t*-statistics from regressions of change in death rates as functions of changes in climate variables and change in other correlates, U.S. counties, 1931–1940: coefficients (*t*-statistics)**

	Dependent variable							
	Change in infant mortality rate				Change in noninfant death rate			
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 1	Spec. 2	Spec. 3	Spec. 4
Constant	–2.869	–1.823	–3.034	–1.532	–0.366	–0.309	–0.350	–0.257
	(–3.36)	(–1.73)	(–3.34)	(–1.43)	(–6.26)	(–3.06)	(–5.19)	(–2.55)
Change in inches of precipitation during year	0.007	–0.002	0.005	0.005	–0.002	–0.003	–0.003	–0.002
	(0.41)	(–0.13)	(0.25)	(0.23)	(–1.4)	(–1.58)	(–1.27)	(–1.17)
Change in average daily high temperature	0.001	0.050			0.005	–0.001		
	(0)	(0.27)			(0.29)	(–0.04)		
Change in share of days with high temperatures between:								
High ≥ 100			–15.499	–4.053			–0.320	–0.447
			(–1.15)	(–0.28)			(–0.24)	(–0.33)
100 > high ≥ 90			–19.015	–16.892			–2.335	–2.438
			(–1.17)	(–1.14)			(–2.05)	(–2.12)
90 > high ≥ 80			–12.930	–7.543			–1.702	–1.721
			(–1.02)	(–0.62)			(–1.82)	(–1.84)
80 > high ≥ 70			–19.488	–19.481			–3.076	–3.217
			(–1.23)	(–1.24)			(–2.96)	(–2.96)
70 > high ≥ 60			–12.959	–14.077			–0.996	–1.190
			(–0.92)	(–1.03)			(–1.24)	(–1.46)
60 > high ≥ 50			—	—			—	—
50 > high ≥ 40			–25.799	–19.539			–0.793	–1.127
			(–1.90)	(–1.58)			(–0.90)	(–1.35)
40 > high ≥ 30			–18.553	–17.970			–1.561	–1.348
			(–1.63)	(–1.65)			(–2.33)	(–1.89)
30 > high ≥ 20			–6.591	–7.066			–2.674	–2.142
			(–0.52)	(–0.58)			(–3.17)	(–2.65)
20 > high ≥ 10			–52.942	–42.102			0.117	0.292
			(–3.90)	(–3.30)			(0.08)	(0.20)
10 > high > 0			27.853	28.578			1.096	1.433
			(0.80)	(0.87)			(0.55)	(0.76)

0 > high ≥ –10		–53.798	–32.765		–12.052	–11.301
		(–1.21)	(–0.88)		(–4.44)	(–4.02)
–10 > high		–149.597	–74.660		0.454	3.049
		(–2.50)	(–1.23)		(0.07)	(0.62)
Change in:						
Results of bovine tuberculosis testing	0.525		0.470	–0.032		–0.030
	(1.19)		(1.05)	(–1.14)		(–1.08)
Hospital beds per female aged 15–44 potentially available for infants	0.077		0.077	0.002		0.002
	(1.98)		(2.00)	(1.56)		(1.61)
Births per woman aged 15–44	–0.261		–0.262	0.018		0.018
	(–7.51)		(–7.42)	(8.69)		(8.67)
Retail sales per capita	0.027		0.029	0.001		0.001
	(2.84)		(2.92)	(0.75)		(1.16)
% owning radio	–0.171		–0.192	0.002		0.000
	(–2.28)		(–2.67)	(0.24)		(–0.06)
Auto registrations per capita	13.967		12.396	0.575		0.439
	(0.87)		(0.80)	(0.62)		(0.52)
Crop value	0.000		0.000	0.000		0.000
	(–0.32)		(–0.33)	(–0.2)		(–0.03)
Tax Returns Filed Per Capita	–3.417		3.865	2.563		2.806
	(–0.24)		(0.25)	(2.11)		(2.03)
Public Works Admin. Grants Per Capita	–0.024		–0.024	0.001		0.002
	(–1.01)		(–1.01)	(1.31)		(1.52)
Agricultural Adjustment Administration grants per capita	0.029		0.029	0.003		0.002
	(1.14)		(1.13)	(1.87)		(1.46)
Relief grants per capita	0.020		0.018	0.008		0.007
	(0.6)		(0.53)	(3.14)		(2.85)
Public Roads Administration grants per capita	0.163		0.162	–0.006		–0.005
	(0.72)		(0.72)	(–0.57)		(–0.53)
Disaster Loan Corporation loans per capita	–0.086		–0.118	–0.090		–0.088
	(–0.18)		(–0.24)	(–2.4)		(–2.36)

(*continued*)

Table 5.4 (continued)

	Dependent variable							
	Change in infant mortality rate				Change in noninfant death rate			
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 1	Spec. 2	Spec. 3	Spec. 4
Farm loans per capita		0.048		0.053		0.006		0.005
		(0.93)		(1.03)		(2.18)		(2.03)
Reconstruction Finance Corporation loans per capita		–0.094		–0.094		–0.001		–0.002
		(–1.67)		(–1.65)		(–0.48)		(–0.49)
U.S. Housing Authority loans per capita		–0.007		0.001		–0.010		–0.009
		(–0.12)		(0.01)		(–2.66)		(–2.25)
Civilian Conservation Corps camps established in year *t*		0.016		0.000		–0.002		–0.004
		(0.08)		(0.00)		(–0.12)		(–0.28)
Year dummies								
Year 1932	–0.812	0.941	–0.409	0.827	0.381	0.363	0.411	0.371
	(–0.58)	(0.62)	(–0.26)	(0.51)	(4.31)	(3.93)	(3.67)	(3.09)
Year 1933	3.700	2.518	3.981	2.487	0.227	0.261	0.200	0.221
	(2.56)	(1.39)	(2.86)	(1.39)	(2.47)	(2.28)	(2.12)	(1.91)
Year 1934	4.665	3.819	4.714	3.326	0.728	0.453	0.685	0.379
	(3.28)	(2.44)	(3.24)	(2.13)	(7.35)	(3.57)	(7.11)	(3.10)
Year 1935	–0.720	–2.869	–0.697	–3.190	0.294	0.194	0.257	0.133
	(–0.49)	(–1.81)	(–0.45)	(–1.81)	(2.93)	(1.79)	(2.29)	(1.04)
Year 1936	3.510	2.642	4.118	2.387	0.863	0.871	0.846	0.799
	(3.4)	(2.05)	(3.61)	(1.94)	(9.19)	(6.68)	(9.02)	(5.99)
Year 1937	0.188	–0.974	0.015	–1.152	–0.072	–0.165	–0.075	–0.194
	(0.14)	(–0.64)	(0.01)	(–0.71)	(–0.76)	(–1.56)	(–0.87)	(–1.88)
Year 1938	0.474	1.339	0.570	1.207	–0.192	–0.260	–0.134	–0.225
	(0.31)	(0.75)	(0.34)	(0.67)	(–1.87)	(–1.96)	(–1.19)	(–1.62)
Year 1939	0.428	–1.177	0.519	–1.613	0.294	0.193	0.221	0.093
	(0.31)	(–0.76)	(0.35)	(–0.95)	(5.13)	(2.66)	(2.70)	(0.96)
Year 1940	1.680	2.674	2.002	2.391	0.456	0.406	0.450	0.343
	(1.07)	(1.69)	(1.14)	(1.43)	(6.07)	(3.17)	(5.21)	(2.59)

Note: The regressions have White-corrected robust standard errors (in parentheses), which are clustered at the state level.
Dash indicates reference temperature band.

This still would not resolve the problem if there were serial correlation in the death rates.[11]

The measure of economic activity, retail sales per capita, displays a positive relationship with infant mortality rates during the 1930s. It has long been thought that improved incomes would reduce infant mortality rates (Antonovsky and Bernstein 1977; Clifford and Brannon 1978; Dehejia and Lleras-Muney 2004; Kaplan et al. 1996; Kennedy, Kawachi, and Prothrow-Stith 1996; and Waldmann 1992). Recently, however, much evidence has emerged to challenge this commonplace assumption. For example, Fishback, Haines, and Kantor (2007) found a positive relationship between economic activity and several types of death rates in their fixed effects estimates using a panel of annual data for 114 cities between 1929 and 1940. Christopher Ruhm (2000) also found similar procyclical effects for various death rates in fixed effects analyses in the 1970s, 1980s, and 1990s. Further in the past, the antebellum puzzle is perhaps the quintessential example of rising death rates having been associated with increased economic activity. Haines, Craig, and Weiss (2003) show that the positive correlation between economic activity and poor health is driven, in part, by the greater transmission of germs during associated with movement of people and goods. Nor, it should be noted, was this dynamic limited to the United States. In early stages of development, England and Wales also exhibited a negative correlation between health and growth (Fogel 1994; Steckel 1992). In a study of yellow fever and smallpox, Beeson and Troesken (2006) find evidence that severe epidemics were positively correlated with economic activity. Fast growing port cities were ripe targets for the inflow of new infections and new populations of vulnerable (i.e., previously unexposed) migrants; sleepy backwaters did not have such a dubious honor.

Due to problems with pollution from leaded gasoline, we had expected a substantial effect of the change in automobile registrations on infant mortality. More automobiles led to more lead emissions from the leaded gasoline that was widely used at this time. It has long been suspected that lead emissions harm fetal and infant development. In fact, the phase out of leaded gasoline during the 1970s was associated with small but statistically significant reduction is in infant mortality (Reyes 2002). Similarly, Greenstone and Chay (2003) find that reductions in pollutants are associated with lower infant mortality in cities in the modern era. However, the coefficients of automobile

11. In a separate unreported analysis, the positive relationship between hospital beds and infant mortality was essentially eliminated in the years after 1936 when the use of sulfa drugs had spread throughout the nation. Thomasson and Treber (2008) found that the number of deaths of mothers during child birth had been slightly negatively related to the number of hospital beds for most of the period from 1920 through 1936. They found evidence that there was a greater likelihood of sepsis infections in hospitals than outside hospitals. Doctors could do little about the infections into the introduction of sulfa drugs throughout the country around 1937. However, once the drugs were available, there was a more negative correlation between access to hospitals and maternal mortality.

registrations per capita in table 5.4 imply that a 1-percent rise in automobile registrations would have been associated with less than a 0.02 percent rise in infant mortality and the effect is statistically insignificant.

There is weak evidence that greater problems with bovine tuberculosis (BTB) were associated with greater infant mortality. Alan Olmstead and Paul Rhode (2008) have reported that large numbers of children and infants were killed by the transmission of the disease into the milk supply from diseased dairy cattle in the late 1800s and early 1900s. An extensive BTB eradication program between 1900 and 1930 had greatly diminished the problem but not fully eliminated it. Bovine tuberculosis was much less widespread in the 1930s and may have been less virulent. The positive coefficient suggests still some effects, but the coefficient is not statistically significant.

Areas with higher general fertility rates, births per woman aged fifteen to forty-four, were associated with lower infant mortality rates. Measures of spending and loan activity from a series of major New Deal programs are also included. None of the programs appear to have strong reductive effects on infant mortality. There is the potential of endogeneity bias that might have weakened the effectiveness of the programs. When Fishback, Haines, and Kantor (2007) controlled for endogeneity bias in their study of major cities in the 1930s, they found evidence that greater relief spending helped reduce infant mortality rates.

5.5 Climate, Weather, and Death Rates for the Noninfant Population

The relationships between climate/weather and mortality rates for the rest of the population above the age of one are similar to what we see for infant mortality rates. As in the case of infant mortality, greater literacy and more access to radios and magazines are associated with lower death rates. A feature that is different from the infant mortality pattern, however, is that adding the information variables to a specification that includes only climate/weather variables does not change the relationship between noninfant mortality and climate. The real test, however, is what happens when we add the measures of access to knowledge to specifications that include all correlates. As was the case with infant mortality, the addition of the information variables reduced the effects of climate/weather are reduced. This finding highlights once again the importance of controlling for access to knowledge when measuring the impact of climate on death rates. Without such controls, other studies might well overstate the impact of temperature on mortality.

Tables 5.5 and 5.6 document these patterns. In table 5.5, the climate/weather patterns are measured with the average high temperature for the year and the total inches of precipitation during the year. The simplest relationships in specification (1) show that higher noninfant mortality is associated with lower average temperatures and more precipitation. The addition of the information variables to the simplest specification, moving from specification (1) to those in columns (2) and (3), has little impact on

Table 5.5 **Coefficients and *t*-statistics from regressions of noninfant deaths per thousand people on annual average high temperature, annual precipitation, and other correlates**

	Coefficient (*t*-statistics)				
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
Average daily high temperature in year	–0.051	–0.063	–0.032	0.022	–0.033
	(–2.12)	(–2.12)	(–1.61)	(1.62)	(–3.34)
Inches of precipitation during year	0.031	0.028	0.043	0.006	–0.002
	(2.63)	(2.4)	(4.94)	(1.39)	(–0.42)
% illiterate		0.038	0.127		0.134
		(0.96)	(3.35)		(3.61)
% owning radio			–0.009		–0.053
			(–1.73)		(–10.1)
Per capita circulation of 15 magazines, 1929			0.151		–0.021
			(9.58)		(–2.48)

Notes: The regressions have White-corrected robust standard errors, which are clustered at the state level. Reported R^2 range from 0.039 to 0.22. The remaining correlates are retail sales per capita; auto registrations per capita; tax returns filed per capita; crop value; percent home ownership; Public Works Administration grants per capita, Agricultural Adjustment Administration grants per capita; relief grants per capita; Public Roads Administration grants per capita; Disaster Loan Corporation loans per capita; farm loans per capita, Reconstruction Finance Corporation loans per capita; U.S. Housing Authority loans per capita; Civilian Conservation Corps camps established in year t; Civilian Conservation Corps camps established in year $t-1$; Civilian Conservation Corps camps established in year $t-2$; hospital beds per female aged fifteen to forty-four potentially available for infants; employment in polluting industries, 1930; coal tonnage; results of bovine tuberculosis testing; births per woman aged fifteen to forty-four; percent of population aged five to nine, ten to fourteen, fifteen to nineteen, twenty to twenty-four, twenty-five to twenty-nine, thirty to thirty-four, thirty-five to forty-four, forty-five to fifty-four, fifty-five to sixty-four, sixty-five to seventy-four, and seventy-five and over; percent urban; percent foreign-born; percent African American; population per square mile; percent families with electricity; manufacturing employment per capita; retail employment per capita; number of lakes; number of swamps; maximum elevation; elevation range; percent church membership; number of rivers that pass through eleven to twenty counties in county; number of rivers that pass through twenty-one to fifty counties in county; number of rivers that pass through over fifty counties in county; number of bays; number of beaches, on Atlantic Coast, on Pacific Coast, on Gulf Coast, on Great Lakes; land area in square miles; and a constant term.

the relationship between climate/weather and noninfant mortality. When we add all of the correlates except the information variables in specification (4), the relationship between noninfant mortality and the average daily high temperature switches signs from negative to positive. Further, the positive relationship with precipitation is cut dramatically from a statistically significant 0.03 in column (1) to 0.006 in column (4). The addition of the information variables to specification (4) to create specification (5) causes the temperature coefficient to switch signs again to a negative and statistically significant –0.033. Meanwhile, the precipitation coefficient turns negative but with an even smaller magnitude than in specification (4). The importance of access to knowledge is highlighted by the statistically significant positive relationship of noninfant mortality with the percent illiterate and the negative coefficients on radio ownership and magazine circulation.

When climate/weather is measured with the share of days in each

Table 5.6 **Coefficients and *t*-statistics from regressions of noninfant mortality rate on share of days during year in temperature bands; annual precipitation, and other correlates**

	Coefficient (*t*-statistics)				
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
Share of days in year that high temperature					
High ≥ 100	5.9253199	6.245898	5.6537376	4.0611318	2.3489633
	(1.74)	(1.89)	(1.7)	(2.04)	(1.48)
100 > high ≥ 90	–4.427665	–5.8174	–5.11953	–2.09142	–3.10996
	(–1.44)	(–1.9)	(–2.07)	(–1.33)	(–2.97)
90 > high ≥ 80	3.0792415	2.030206	–0.01870	0.1518418	–1.1193712
	(1.2)	(0.71)	(–0.01)	(0.12)	(–1.12)
80 > high ≥ 70	6.4659766	4.723384	–1.21041	1.0813113	–0.8415495
	(2.3)	(1.62)	(–0.51)	(0.78)	(–0.73)
70 > high ≥ 60	3.6034486	2.368396	–0.76792	1.5105014	0.3858891
	(1.48)	(0.93)	(–0.37)	(0.97)	(0.27)
60 > high ≥ 50	—	—	—	—	—
50 > high ≥ 40	5.2266821	5.455708	0.7692672	–0.34326	1.242737
	(1.29)	(1.3)	(0.26)	(–0.25)	(1)
40 > high ≥ 30	8.114672	8.473622	3.3481582	–2.72522	–0.6973798
	(2.5)	(2.64)	(1.06)	(–1.66)	(–0.49)
30 > high ≥ 20	–3.238951	–3.79263	–1.16735	–0.37342	0.76637834
	(–0.86)	(–1.01)	(–0.34)	(–0.18)	(0.36)
20 > high ≥ 10	6.430615	6.184703	3.7969074	–0.253966	3.4170776
	(0.99)	(0.97)	(0.74)	(–0.09)	(1.29)
10 > high > 0	–31.83301	–31.803	–21.71878	–12.8939	–3.1538209
	(–2.74)	(–2.76)	(–2.17)	(–2.31)	(–0.67)
0 > high ≥ –10	–26.27229	–28.8894	–26.97869	–3.27581	–0.9729119
	(–2.16)	(–2.4)	(–2.43)	(–0.7)	(–0.29)
–10 > high	28.442934	24.24312	18.496452	39.282855	33.403666
	(1.6)	(1.37)	(1.23)	(5.39)	(4.88)
Inches of precipitation during year	0.025201	0.022298	0.0436157	0.0048751	0.00116884
	(2.08)	(1.93)	(4.45)	(1.04)	(0.26)

Note: See table 5.5 notes.
Dash indicates reference temperature band.

temperature band in the table 5.6 regressions, the same pattern still arises. When no correlates aside from climate are included in the analysis in specification (1) in table 5.6, noninfant mortality is higher with greater precipitation. The temperature comparisons are relative to the share of days when the high temperature is in the 50s. Noninfant mortality is statistically significantly higher when there were relatively more days with high temperatures exceeding 100°, in the 70s, in the 30s, and below minus 10°. It was lower when there were more days in between 0° and 10° and between –10° and 0°.

When we add all correlates except the information variables to create specification (4) the precipitation coefficient is cut by three-fourths, while the only statistically significant temperature band coefficients are at the extremes. Temperatures over 100° and under minus 10° are associated with higher death rates, while temperatures in the 0° to 10° ranges were associated with lower death rates. When the information correlates are added in specification (5) in table 5.6, the coefficient of the over 100° temperature band is cut nearly in half, and the coefficient at the other extreme is cut by about 15 percent.

The impact of weather fluctuations on noninfant mortality are examined by using differencing to control for long-run climate and other time-invariant factors in specifications (N-1) through (N-4) in table 5.4. We also incorporate time fixed effects to control for nationwide shocks. Like the situation with infant mortality, fluctuations in the annual average high temperature and precipitation had small and statistically insignificant effects on changes in noninfant mortality with and without other time-varying covariates. When we examine the differences in the number of days in different temperature bands, there are statistically significant effects. The coefficients of the changes in the share of days in the 90s, 80s, 70s, 30s, 20s, and between 0 and minus 10 all were statistically significant and negative. However, the economic magnitude of the effects are even smaller than they were for infant mortality. None of the elasticities are more negative than –0.034.

The coefficients of the remaining correlates in table 5.4 show that annual noninfant death rates also rose with increases in the number of hospital beds, the general fertility rate, a higher share of the population with enough income to pay federal income taxes, and in areas where the New Deal spent more per capita on relief programs and the farm programs, both loans and Agricultural Adjustment Act (AAA) grants. Death rates were lower in areas where more was spent on loans from the Disaster Loan Corporation.

5.6 Conclusions

Climate and health interact in a variety of complex ways that are strongly influenced by human decisions, locations, insect and animal populations, and a variety of different factors. We explore the raw correlations between climate and mortality during the Great Depression to see if we can discern any patterns and then incorporate a wide range of demographic, economic, and geographic correlates to examine whether the raw correlations are still present. The results show that variations across the country in climate were associated with differences in infant mortality and noninfant death rates. However, much of the influence of climate is muted once the other correlates are included.

One key finding in the study is the importance of controlling for access to information when measuring the relationship between mortality and climate. In specifications where measures of access to information are not included, the results often show a strong positive relationship between mortality and temperature. However, that relationship appears to be due to a positive bias arising from the omission of measures of access to knowledge. When measures of illiteracy, access to radios, and access to magazines are incorporated in the analysis, the strong positive relationship between mortality and temperature is no longer present.

Public health scholars have long touted the health benefits of improved information flows during the campaigns to promote public health during the 1910s, 1920s, and 1930s. Certainly, we saw sharp declines in infant mortality during this period that cannot be fully explained by changes in income and sanitation. The results here provide support for this view. Both infant mortality and noninfant mortality rates were higher in areas where there was more illiteracy and lower in areas where people had more access to radios and the circulation of news magazines was greater. These effects are not just indirectly related to higher incomes because we control for urbanization and economic activity in the analysis.

Finally, the results suggest that differences in climate rather than fluctuations in weather around the long-term climate norms have bigger effects on mortality. In Chicago in the late 1800s, the differences in mortality due to pneumonia were much higher in July and August than in the rest of the year, while fluctuations in temperature around the normal differences across months had relatively weak effects. In the county sample, the results show strong effects of weather when we do not control for time-invariant features of the climate. Once we control for the time-invariant features of the climate, the impact of weather fluctuations around the core climate are not very large.

There is still much to explore about the relationship between climate, weather, and mortality. This is just a start that focuses on overall mortality rates. We plan further work to examine the specific weather patterns that scholars have identified for specific diseases. The specific mechanisms identified for these diseases can be complicated. As one example, St. Louis encephalitis (SLE) was the name given a disease that led to 1095 hospital cases and 201 deaths in St. Louis in the summer of 1933.[12] St. Louis encepha-

12. Scholars suggest that Paris, Illinois reported thirty-eight cases and fourteen deaths from the same disease in 1932 but somehow escaped having the disease named after the town (Chamberlain 1980, 7).

litis is a mosquito-borne disease as well, but Thomas Monath (1980) found that later epidemics were typically associated with above-average temperatures and abnormally high precipitation in January and February, below normal temperature in April, above-average temperatures in May through August, and an abnormally dry July. In general, the warm conditions help the virus multiply within the mosquito population and the other requirements (e.g., for April) are associated with specific life-cycle events in the host populations. The conditions in St. Louis during the year of 1933 epidemic fit Monath's ideal conditions. The winter of 1932 to 1933 was the second warmest on record, April was cool, and June through August were the driest months on record (Reiter 1988, 245–55). Other studies suggest that fluctuations in temperature throughout the day and throughout the month may influence the extent of the disease. More work, therefore, is needed to take the specific bioscience conditions into account when designing the weather variables used for further study.

Appendix

Data Source

The sources of information for the weather, death rates, and birth information are in the text. Population in 1910 and 1930, percent illiterate in 1930, percent of families with radios in 1930 and 1940, retail sales in 1929 and 1939, crop values in 1929 and 1939, percent homeowners in 1930 and 1940, percent urban in 1930 and 1940, percent foreign-born in 1930 and 1940, percent African American in 1930 and 1940, population density in 1930 and 1940, manufacturing employment in 1929 and 1939, and retail employment in 1929 and 1939 can be found in the data sets incorporated into Michael Haines (2004) ICPSR 2896 data set. Percent illiterate in 1940 was calculated using procedures developed in U.S. Bureau of the Census 1948 from data on education in Haines (2004). Retail sales in 1933 and 1935 are from U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce (1936, 1939). Information on the number of federal individual income tax returns filed in county for 1929 is from U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce (1932); 1930, 1933, 1937, and 1938 from U.S. Bureau of Internal Revenue (1932, 1935, 1939, and 1940, respectively); 1931, 1932, 1935, 1936, and 1939 from Rand McNally (1934, 1935, 1938, 1939, and 1943, respectively); 1934 from U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce (1939). Information on the number of hospital beds in each county was compiled by Melissa Thomasson from reports by the American Medical Association (various years). See Thomasson and Treber (2008) for more details. Data for the New Deal programs by county and state come from U.S. Office of Government Reports (1940a, b, respectively). Auto registrations by county in 1930 are from U.S. Bureau of Foreign and Domestic Commerce (1932). Auto registrations by county in 1931 are from the October 31, 1931 issue of *Sales Management.* County auto registrations in 1936 are from U.S. Bureau of Foreign and Domestic Commerce (1939). Annual state automobile registrations are from U.S. Public Roads Administration (1947). Circulation of fifteen national magazines as of January 1, 1929 is from U.S. Bureau of Foreign and Domestic Commerce (1936).

The number of Civilian Conservation Corps camps started in fiscal year *t* in each county were determined by starting with camp lists from the Civilian Conservation Corps Legacy Web site. We then added some additional camps listed in the U.S. National Archives finding aid for Record Group 35, Civilian Conservation Corp. The camp lists listed the nearest railroad station and the nearest post office. We matched the camps to post offices by downloading post office locations by county from the http://www.usps.com/postmasterfinder/welcome.htm Web site in 2007. The number of people employed in polluting industries of chemicals, cigars and cigarettes, glass, bread, meat packing, autos, iron and steel, nonmetals, planing mills, lumber mills, boots and shoes, printing, paper, cotton textiles, and rubber comes from U.S. Bureau of the Census, *Fifteenth Census* (1932). Population by age group in 1930 and 1940 is found in Gardner and Cohen (1992). Results of Bovine Tuberculosis Status tests are discussed in Olmstead and Rhode (2007), and the data are from U.S. Bureau of Animal Industry (various years). County coal tonnage is estimated by using the number gainfully employed in coal mining in 1930 in each county from U.S. Bureau of the Census, *Fifteenth Census* (1932), and the coal produced in 1929 from U.S. Bureau of the Census (1933a) to determine a figure for tonnage per miner in each county. A ratio of coal miners in 1930 in the county to coal miners in 1930 in the county was then determined. The number of miners in each county for the other years of the 1930s was then determined by multiplying the county/state employment ratio in 1930 by the state coal employment from the U.S. Bureau of Mines (various years) for each year. Then the ratio of coal tonnage per miner was multiplied by the estimated county employment to obtain coal tonnage in each year. The sources and information on coastal location, access to large rivers, and topographical information are described in Fishback, Horrace, and Kantor (2006) and are available online at http://economics.eller.arizona.edu/faculty/fishback.asp under data sets from published research studies. The number of church members is from church membership data from the *Census of Religious Bodies, 1926,* as reported in U.S. Bureau of the Census (1980).

Table 5A.1 Summary statistics and discussion of nature of data used in panel

Description	All years or interpolation procedure	Mean	SD
Infant mortality rate, number of infant deaths per thousand live births	All years	56.633	28.094
Noninfant mortality rate, number of deaths of people over age one per thousand population	Deaths all years, population in 1930, 1940, and straight-line interpolation in between	10.063	3.158
Percent illiterate	1930, 1940, straight-line interpolation in between	5.541	5.337
Percent families with radios	1930, 1940, straight-line interpolation in between	48.174	22.834
Circulation of 15 national magazines as of January 1, 1929 per person in 1930	1929, same value throughout	15.081	10.656
Retail sales per capita	1929, 1933, 1935, 1939, interpolated using state personal income in between	193.469	108.174
Auto registrations per capita	1930, 1931, 1936, interpolated using state information in between	0.163	0.158
Tax returns per capita	All years	0.020	0.024
Crop values	1929, 1939, interpolated using state information on crop value in between	1,749,595	2,060,620
Percent homeowners	1930, 1940, straight-line interpolation in between	51.310	12.575
Public Works Administration federal and nonfederal grants per capita	County total for June 1933 through June 1939 distributed using state information	1.758	31.416
Agricultural Adjustment Administration grants per capita	County total for June 1933 through June 1939 distributed using state information	5.550	17.256
Relief spending per capita by WPA, FERA, CWA, SSA, and FSA grants	County total for June 1933 through June 1939 distributed using state information	5.935	8.854
Public Roads Administration grants per capita	County total for June 1933 through June 1939 distributed using state information	2.395	5.157
Disaster Loan Corporation loans per capita	County total for June 1933 through June 1939 distributed using state information	0.007	0.166

(*continued*)

Table 5A.1 (continued)

Description	All years or interpolation procedure	Mean	SD
Farm loans per capita	County total for June 1933 through June 1939 distributed using state information	3.639	7.672
Reconstruction Finance Corporation loans per capita	County total for June 1933 through June 1939 distributed using state information	1.466	5.087
U.S. Housing Authority loans per capita	County total for June 1933 through June 1939 distributed using state information	0.043	0.902
No. of Civilian Conservation Corps camps started in fiscal year t	All years	0.173	0.650
No. of Civilian Conservation Corps camps started in fiscal year $t-1$	All years	0.161	0.639
No. of Civilian Conservation Corps camps started in fiscal year $t-2$	All years	0.153	0.634
Hospital beds per 1,000 women aged 15–44, hospitals that might help infants	All years	9.100	16.968
No. of people employed in polluting industries of chemicals, cigars and cigarettes, glass, bread, meat packing, autos, iron and steel, nonmetals, planing mills, lumber mills, boots and shoes, printing, paper, cotton textiles, and rubber	1930, same value throughout	2,325.430	13,224.580
County coal tonnage in year t	Coal tonnage based on tonnage/employment ratio in 1930 and then interpolated using state estimates of coal tonnage	170.526	1,479.607
Results of bovine tuberculosis status tests	Annual based on tests in May through July for 1930 through 1937, October in 1938 and 1939, and January 1941 for 1940	1.350	0.748
General fertility rate, births per 1,000 women aged 15–44	Annual birth information divided by trend number of women aged 15–44 interpolated between 1930 and 1940 Census	86.013	24.757
Percent of population			
Aged 5–9	1930, 1940, straight-line interpolation in between	10.380	1.869

Aged 10–14	1930, 1940, straight-line interpolation in between	10.359	1.514
Aged 15–19	1930, 1940, straight-line interpolation in between	10.074	1.208
Aged 20–24	1930, 1940, straight-line interpolation in between	8.578	0.993
Aged 25–29	1930, 1940, straight-line interpolation in between	7.506	0.990
Aged 30–34	1930, 1940, straight-line interpolation in between	6.754	0.917
Aged 35–44	1930, 1940, straight-line interpolation in between	12.295	1.554
Aged 45–54	1930, 1940, straight-line interpolation in between	10.337	1.640
Aged 55–64	1930, 1940, straight-line interpolation in between	7.319	1.770
Aged 65–74	1930, 1940, straight-line interpolation in between	4.535	1.472
Aged 75+	1930, 1940, straight-line interpolation in between	1.961	0.810
Percent urban	1930, 1940, straight-line interpolation in between	21.856	24.529
Percent foreign-born	1930, 1940, straight-line interpolation in between	4.287	5.271
Percent African American	1930, 1940, straight-line interpolation in between	10.883	18.160
Population density	1930, 1940, straight-line interpolation in between	103.603	780.869
Percent of families with electricity	1930, 1940, straight-line interpolation in between	49.156	27.816
Manufacturing employment as a percentage of the population	Manufacturing employment in 1930, 1940, interpolated between years using census of manufacturing county evidence for 1929, 1931, 1933, 1935, 1937, and 1939, and state information on manufacturing employment in between, population is 1930 and 1940 with straight-line interpolation in between	4.956	45.592
Retail employment as a percentage of the population	1930, 1940, straight-line interpolation in between	1.990	1.282
Average number of lakes in county	Same value throughout	21.442	56.027
Average number of swamps in county	Same value throughout	2.417	8.110
Average max elevation in county	Same value throughout	2,415.793	2,989.049
Average elevation range in counties	Same value throughout	1,539.714	2,382.894
Percent church members 1926/population 1930	Same value throughout	48.228	23.451
Average number of rivers that pass through 11–20 counties in county, population weight	Same value throughout	0.241	0.452

(*continued*)

Table 5A.1 (continued)

Description	All years or interpolation procedure	Mean	SD
Average number of rivers that pass through 21–50 counties in county, population weight	Same value throughout	0.136	0.372
Average number of rivers that pass through 51 and over counties in county, population weight	Same value throughout	0.093	0.296
Average number of bays in county	Same value throughout	3.107	14.143
Average number of beaches in county	Same value throughout	0.510	3.193
County on Atlantic Ocean	Same value throughout	0.044	0.205
County on Pacific Ocean	Same value throughout	0.014	0.117
County on Gulf of Mexico	Same value throughout	0.017	0.128
County on Great Lakes	Same value throughout	0.028	0.165
1930 area in square miles	1930, same value throughout	969.230	1,329.276
Average daily high temperature, Fahrenheit	All years, nearest weather station if no station in county	67.7	8.3
No. of inches of precipitation	All years, nearest weather station if no station in county	35.2	15.0
Percentage of days with high temperature within temperature band			
High ≥ 100	All years, nearest weather station if no station in county	0.023	0.037
100 > high ≥ 90	All years, nearest weather station if no station in county	0.134	0.081
90 > high ≥ 80	All years, nearest weather station if no station in county	0.198	0.067
80 > high ≥ 70	All years, nearest weather station if no station in county	0.172	0.038
70 > high ≥ 60	All years, nearest weather station if no station in county	0.144	0.040
60 > high ≥ 50	All years, nearest weather station if no station in county	0.119	0.039
50 > high ≥ 40	All years, nearest weather station if no station in county	0.096	0.050
40 > high ≥ 30	All years, nearest weather station if no station in county	0.070	0.058
30 > high ≥ 20	All years, nearest weather station if no station in county	0.028	0.033
20 > high ≥ 10	All years, nearest weather station if no station in county	0.011	0.017
10 > high > 0	All years, nearest weather station if no station in county	0.004	0.009
0 > high ≥ –10	All years, nearest weather station if no station in county	0.001	0.005
–10 > high	All years, nearest weather station if no station in county	0.000	0.002

Note: SD = standard deviation; WPA = Works Progress Administration; FERA = Federal Emergency Relief Administration; CWA = Civil Works Administration; SSA = Social Security Administration; FSA = Farm Security Administration.

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