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# Annual Variations in Deaths by Age, Deaths by Cause, Prices, and Weather in London 1670 to 1830*

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They starve and freeze and rot among themselves...
H. Fielding, Bow Street Magistrate, 1753, in reference to the London poor.[1]

Could the Display herewith exhibited be viewed with confidence in respect to unerring accuracy, in the distinction and specification of the Diseases, and the numbers reported under each head, it might justly be regarded as the most interesting Statistical Picture ever submitted to human attention; and more particularly so, could it have been accompanied by a corresponding display of the changes, extremes, and general state of the atmosphere in each year during the sample period.

J. Marshall, 1832, *Mortality of the Metropolis...*[2]

London was the largest city in Europe in the eighteenth century having grown from 400000 inhabitants in 1650 to over one million by 1811. The great metropolis was home to about eleven per cent of the English population in 1750 and it is estimated that at least one-sixth of the total adult population of England spent some portion of their lives in London.[3] The present inquiry investigates the impact of annual variations in grain prices and weather on annual fluctuations in deaths by age and deaths by cause in London between 1670 and 1830. To that end Marshall's[4] extensive recapitulation of deaths by age and by cause in London was supplemented by Beveridge's[5] and Mitchell and Deane's[6] calendar year wheat prices, Manley's[7] compilation of monthly temperature readings in Central England beginning in 1659, and Wales-Smith's[8] monthly rainfall figures from Kew, a suburb of London, which start in 1697. Making use of an appropriate method

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[1] M. D. George, *London Life in the Eighteenth Century* (New York: Capricorn, 1965), p. 12.

[2] J. Marshall, *Mortality of the Metropolis, a Statistical View of the Number of Persons Reported to have Died, of each of more than 100 Kinds of Diseases and Casualties within the Bills of Mortality, in each of the Two Hundred and Four Years, 1629–1831* (London: Treuttel, Würtz and Richter, 1832), pp. iii, iv.

[3] E. A. Wrigley, 'A simple model of London's importance in changing English society and economy 1650–1750', in *Towns and Societies: Essays in Economic History and Historical Sociology*, ed. P. Abrams and E. A. Wrigley (Cambridge: University Press, 1978), pp. 215–243, and E. A. Wrigley and R. S. Schofield, *The Population History of England 1541–1871, A Reconstruction* (London: Edward Arnold, 1981) p. 66.

[4] Marshall, *op. cit.* in footnote 2.

[5] W. Beveridge, *Prices and Wages in England from the Twelfth Century to the Nineteenth Century* (London: Longmans, Green and Co., 1939), vol. 1.

[6] B. R. Mitchell and P. Deane, *Abstract of British Historical Statistics* (Cambridge University Press, 1962).

[7] G. Manley, 'Central England temperatures: monthly means 1659 to 1973', *Quarterly Journal of the Royal Meteorological Society*, **100** (1974), pp. 389–405.

[8] B. G. Wales-Smith, 'Monthly and annual totals of rainfall representative of Kew, Surrey, from 1697 to 1970', *The Meteorological Magazine*, **100**, 1193 (1971), pp. 345–362.

derived from Lee's[9] work on variations in English vital rates, prices, and weather, the analysis produces results that shed some light on the year-to-year mortality experience of Londoners and allows for some speculation about the factors involved in the determination of urban mortality in the eighteenth century, perhaps justifying some of Marshall's early enthusiasm.

The mechanism by which price increases lead to increased mortality is fairly straightforward. Among persons living at or near the subsistence level annual variations in food supply per head can be approximated by annual variations in the average real wage. In the short run, fluctuations in the price of grain were the primary determinants of variations in the real wage. This is a result of the empirical observation that from year to year nominal wages rarely fluctuated while prices tended to vary substantially. It has been argued by many, including Graunt[10] in reference to London, that few persons actually died of starvation during poor harvest years. The increase in deaths was rather a function of the increased susceptibility of the body to various diseases as a result of malnourishment. An increase in the frequency of interaction among different members of the population as a result of short-term migration might also lead to an increase in the probability of contracting infectious diseases. There exists an extensive literature concerning the impact of annual harvest variations on annual fluctuations in mortality.[11]

The influence of weather on mortality has been a perennial source of debate. Recent appraisals by Howe and Tromp indicate that extremes in climatic variation appear to increase mortality.[12] An increase in day-to-day and week-to-week climatic variability may increase the body's susceptibility to infectious diseases. Howe maintains that 'it is possible to predict with certainty only that extremes of heat and cold are definitely harmful and that moderately hot conditions increase susceptibility to intestinal diseases and moderately cold conditions increase susceptibility to respiratory diseases'.[13] Climatic conditions also affect the mobility and strength of pathogenic micro-organisms and those insects and animals which carry them. It is likely that each disease is individually affected to a greater or lesser extent by variations in food supply and weather.

There is a large literature concerning seasonality of mortality.[14] Buchan and Mitchell's

[9] R. D. Lee, 'Short-term variation: vital rates, prices and weather', in E. A. Wrigley and R. S. Schofield, *op. cit.* in footnote 3, pp. 356–401.

[10] J. Graunt, *Natural and Political Observations made upon the Bills of Mortality* (London: Roycroft, 1662), p. 20.

[11] See for example J. Meuvret, 'Les crises de subsistances et la démographie de la France d'Ancien Régime', *Population*, **1**, 4 (1946), pp. 643–650; P. Goubert, *Beauvais et le Beauvaisis de 1600 à 1730* (Paris: Sevpen, 1960); E. A. Wrigley, *Population and History* (New York: McGraw-Hill, 1969); A. B. Appleby, 'Grain prices and subsistence crises in France and England, 1590–1740', *Journal of Economic History* **39**, 4 (1979), pp. 865–887; and F. Lebrun, 'Les crises démographiques en France aux XVII et XVIII siècles', *Annales, Économies, Sociétés, Civilisations* **35**, 2 (1980), pp. 205–234. For more rigorous statistical analyses see Lee, *op. cit.* in footnote 9; Z. Eckstein, T. P. Schultz, and K. I. Wolpin, 'Short run fluctuations in fertility and mortality in preindustrial Sweden', Center Discussion Paper No. 410, Economic Growth Center, Yale University, 1982; T. Richards, 'Weather, nutrition, and the economy: short-run fluctuations in births, deaths, and marriages, France 1740–1909', *Demography*, **20**, 2 (1983), pp. 197–212; T. Bengtsson and R. Ohlsson, 'Age-specific mortality and short-term changes in the standard of living: Sweden 1751–1860'. Paper presented at the Social Science History Association Annual Meeting in Toronto, 1984; D. R. Weir, 'Life under pressure: France and England, 1670–1870', *Journal of Economic History*, **44**, 1 (1984), pp. 27–47; and E. A. Hammel, 'Short-term demographic fluctuations in the Croatian and Banat military border 1830–47', Program in Population Research Working Paper No. 13, Sub-series in Historical Demography of Southeastern Europe No. 1, University of California, Berkeley, 1984.

[12] G. M. Howe, *Man, Environment and Disease in Britain* (New York: Barnes and Noble, 1972) and S. W. Tromp, *Biometeorology* (London: Heyden and Son, 1980), pp. 149–150, 159, 174, and 225–226.

[13] Howe, *ibid.*, pp.18–19.

[14] Cf. for example M. Sakamoto-Momiyama, *Seasonality in Human Mortality* (Japan: University of Tokyo Press, 1977); L. Bradley, 'An enquiry into seasonality in baptisms, marriages and burials. Part 3. Burial Seasonality', *Local Population Studies*, **6**, (1971), pp. 15–50; and A. Buchan and A. Mitchell, 'The influence of weather on mortality from different diseases and at different ages', *Journal of the Scottish Meteorological Society*, **4**, (1875), pp. 187–265.

detailed analysis of seasonality of deaths by cause in London 1845 to 1874 is exemplary. They find that the incidence of respiratory diseases peaked during the winter months and deaths from bowel complaints peaked during the summer months. Unfortunately, such analyses can tell us little about the impact of unusually cold winters or unusually warm summers on mortality. Bull and Morton's longitudinal analysis is more relevant to the present inquiry. They found that 'changes of temperature of short duration (two to ten days) and of longer duration (15 and more days) are associated with inverse changes in death rates in both respiratory infections (pneumonia and bronchitis) and in vascular diseases (myocardial infarction and cerebral vascular accidents). These relationships are less or absent in young subjects and marked in the elderly'.[15]

Lee's research on England 1541 to 1834, Eckstein *et al.*'s study of Sweden 1756 to 1869, and Richards's investigation of France, 1749 to 1909, incorporate both grain prices (or harvest indices) and climatic variables in attempts to explain annual fluctuations in deaths. Bengtsson and Ohlsson's study of Sweden 1751 to 1860, Hammel's analysis of the Austrian military border in the mid-nineteenth century, and Weir's work on France, 1670 to 1870, also investigate the impact of the harvest on mortality but without weather-related variables.[16] By using distributed-lag models, they find that increases in annual grain prices, decreases in annual real wages, or poor harvests lead to statistically significant increases in mortality. Lee and Eckstein *et al.* found that cold winters tended to increase the death rate in England and Sweden. Lee also found that unusually warm summers increase deaths in England.

There has been no attempt in the literature to investigate the impact of climatic variations on London deaths. Appleby[17] devoted an article to the discussion of nutrition and disease in London from 1550 to 1750. He found little, if any, relationship between his measure of nutrition, London assize bread prices, and disease. This result should be interpreted within the context of Appleby's method. The deaths by cause in London were aggregated by calendar year, the bread assize price was essentially for the harvest year. Thus, the assize price of bread actually reflected only the last three months of the calendar year. Appleby attempted to correct this shortcoming by correlating the assize price of bread with deaths during the following calendar year. This has the unfortunate consequence of eliminating the impact of the harvest (which is generally in September and October) in a given year on deaths in September, October, November and December of the same year. Furthermore, no attempt was made to examine any lagged effects. Finally, it seems likely that whatever impact annual fluctuations in prices might have had on annual variations in deaths from a particular cause over time would have been overwhelmed by the frequent outbreaks of plague, given the unparalleled destructiveness of this disease.

Mirowski[18] used a distributed lags model with a plague dummy variable in his investigation of the relationship between price variations and fluctuations in numbers of deaths in London from 1629 to 1800. He found a significant positive correlation between increases in grain prices and deaths from typhus, smallpox, and fever and total deaths. His analysis did not include weather-related variables.

[15] G. M. Bull and J. Morton, 'Relationships of temperature with death rates from all causes and from certain respiratory and arteriosclerotic diseases in different age groups', *Age and Aging*, **4**, (1975), p. 232.

[16] See footnote 12.

[17] A. B. Appleby, 'Nutrition and disease: the case of London, 1550–1750', *Journal of Interdisciplinary History* **6**, 1 (1975), pp. 1–22.

[18] P. Mirowski, 'The plague and the penny-loaf: the disease dearth nexus in Stuart and Hanoverian London', unpublished manuscript, Department of Economics, University of Michigan, 1976.

Table 1. *Means, standard deviations, and coefficients of variation of the dependent variables*

| | Mean of raw series | Standard deviation of raw series | Coefficient of variation: Raw series | Coefficient of variation: Detrended series |
|---|---|---|---|---|
| London deaths by age 1728 to 1830 | | | | |
| Age 0–1 | 7192 | 1678 | 0.233 | 0.088 |
| 2–4 | 2067 | 356 | 0.172 | 0.156 |
| 5–9 | 821 | 154 | 0.188 | 0.161 |
| 10–19 | 728 | 134 | 0.184 | 0.116 |
| 20–29 | 1620 | 340 | 0.210 | 0.100 |
| 30–39 | 2002 | 360 | 0.180 | 0.102 |
| 40–49 | 2130 | 347 | 0.163 | 0.110 |
| 50–59 | 1814 | 259 | 0.143 | 0.111 |
| 60–69 | 1543 | 230 | 0.149 | 0.120 |
| 70–79 | 1141 | 227 | 0.199 | 0.135 |
| 80–89 | 517 | 125 | 0.242 | 0.145 |
| 90 and over | 86 | 33 | 0.384 | 0.218 |
| Total | 21663 | 3332 | 0.154 | 0.084 |
| London deaths by cause 1670 to 1830 | | | | |
| Typhus (1670–1728) | 143 | 83 | 0.580 | 0.495 |
| Smallpox | 1650 | 816 | 0.495 | 0.372 |
| Fever | 2787 | 1160 | 0.416 | 0.190 |
| Consumption | 4052 | 775 | 0.191 | 0.084 |
| Dropsy | 883 | 141 | 0.160 | 0.113 |
| Apoplexy | 219 | 105 | 0.479 | 0.123 |
| Old Age | 1604 | 443 | 0.276 | 0.124 |
| Infancy* | 7352 | 1849 | 0.251 | 0.069 |
| Diarrhoea | 5636 | 1699 | 0.301 | 0.080 |
| London total deaths 1670 to 1830 | 21853 | 3223 | 0.147 | 0.077 |
| England total deaths 1670 to 1830 | 183888 | 46207 | 0.251 | 0.082 |

* Infancy deaths as defined by Marshall include some deaths from diarrhoea.

### THE PERIOD

The period chosen for this analysis is 1670 to 1830. The series of deaths by cause is not useable until 1647. The last major outbreak of plague occurred in 1666 coinciding with the London Fire. It seems appropriate to examine the impact of prices and the weather on mortality after the disappearance of the plague which tended to dominate annual mortality variations. The period is terminated at 1830 for two reasons: the Bills of Mortality are known to have degenerated in quality during the nineteenth century; after its initial outbreak in 1831 cholera became the new dominating force among epidemic diseases, much like the plague before 1667.

### THE DEPENDENT VARIABLES

The dependent variables along with some summary statistics are presented in Table 1. London deaths by age are available from 1728 onward. The large number of deaths in the middle age groups probably reflects the age distribution of London's population, with greater proportions of the population in the middle age groups than in rural areas, or more aggregated units of analysis.[19] The lack of an age distribution of London's population poses no overwhelming problem when analysing annual fluctuations. Most of the year-to-year variation in the death rate is reflected in the change in the number of deaths themselves provided the population at risk is large relative to the number of deaths.

In Table 1 we show the coefficient of variation for the raw and detrended series. In order to examine short-term variations effectively the long-term trend must be removed from each series. This detrending is done by dividing each data point, $x$, in a series by an eleven-year average of data points centred around $x$.[20] This results in a detrended series which begins five years after the beginning of the raw series and ends five years before its end. Because the mean of a detrended series is nearly unity, the coefficient of variation and the standard deviation of a detrended series are essentially the same. The importance of this detrending procedure will become clear when the method of analysis is discussed.

The first of the useable series of deaths by cause commences with the publication of the reports of Diseases and Casualties in 1629 by the Worshipful Company of Parish Clerks, commonly referred to as the London Bills of Mortality. The series is broken by a large gap from 1637 to 1646, but, thereafter, runs without interruption to the middle of the nineteenth century. The series of deaths by cause is presented by Marshall[21] with appropriate commentary. Each parish clerk appointed two women known as Searchers to visit the house of a deceased person and to report the cause of death. There is some question regarding the validity of the Searchers' judgement. Certainly some causes of death were easily diagnosed since their symptoms were obvious, e.g. plague and smallpox. Others were less distinguishable. Marshall maintains that 'the Searchers, so called, are personages, not perhaps possessing the first order of mental acquirement and discrimination, but possessing plain good sense, matronly deportment, and much practical experience in diseases, affording as fair a guarantee for exactitude in their reports as is likely to be obtained in any other manner, without consulting the medical practitioner by whom the deceased was attended previous to demise'.[22] Over time the diagnosis of certain diseases no doubt changed and any efforts to interpret long-term trends must be speculative at best.[23] However, from year to year, the variations in deaths caused by a particular disease as recorded by the Searchers are likely to be accurate enough for the present analysis.

There are over 150 types of diseases and casualties reported in the Bills of Mortality ranging from common diseases like smallpox, measles, diarrhoea, and consumption to more esoteric causes of death like 'blasted and planetstruck', 'stagnation in the head', 'eaten by lice', and the dreaded 'green sickness'. As shown in Table 1 the categories of deaths by cause chosen for the present analysis are typhus, smallpox, fever, consumption,

[19] London deaths by age groups 1728 to 1830 are from Marshall, *op. cit.* in footnote 2, pp. 70–71. The age groups are 0–1, 2–4, 5–9, 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, 80–89, and 90 and over. The raw data were checked by summing across age groups to match total deaths. Where discrepancies occurred, the questionable number was checked using data gleaned from Birch and *Gentleman's Magazine* by W. A. Hodges, 'The population of London, 1695–1801'. Paper presented at the Conference on British Demographic History, Asilomar, California, 1982. The following errors, probably typographical, were found in Marshall's listing: 1744 ages 5–9 should be 679, not 670; 1760 ages 2–4 should be 1832, not 1822; 1760 ages 40–49 should be 1873, not 1673; 1761 ages 40–49 should be 2088, not 2388; 1769 ages 80–89 should be 383, not 323; 1772 ages 10–19 should be 1056, not 1856; and 1776 ages 30–39 should be 1615, not 1645.

[20] Lee, *op. cit.* in footnote 9, p. 358.

[21] Marshall, *op. cit.* in footnote 2, unpaginated sheets.

[22] Marshall, *op. cit.* in footnote 2, p. iii.

[23] See Ogle's observations regarding the validity of the bills in W. Ogle, 'An inquiry into the trustworthiness of the old bills of mortality', *Journal of the Royal Statistical Society*, **55**, (1892), pp. 437–460.

dropsy, apoplexy, old age, infancy, and diarrhoea.[24] Infancy deaths should not be confused with the modern concept of infant mortality. They are deaths attributable to diseases of infancy and are not necessarily restricted to deaths during the first year of life.

The coefficient of variation of the detrended series is an effective measure of year-to-year variability and consequently can be used to determine which diseases were epidemic and which endemic. Table 1 shows that annual variations were greatest for deaths from typhus, smallpox, and fever which could be considered epidemic diseases. Consumption, dropsy, apoplexy, old age, infancy, and diarrhoea appear to have been endemic.

## THE INDEPENDENT VARIABLES

In Table 2 we show the proposed independent variables along with some summary statistics. Since deaths by age and deaths by cause are aggregated by calendar year it is important that the price series also reflect the calendar year. This criterion eliminates the possible use of the London assize bread price previously discussed. Beveridge[25] has compiled a list of quarterly prices of wheat at Winchester from which calendar-year prices have been calculated. This series begins in 1657 and ends in 1817. It is coupled with the calendar-year price of English wheat which runs from 1771 to 1830 from Mitchell and Deane[26] to form the series of average annual calendar-year wheat prices. This splicing is easily accomplished since the detrended Winchester and English wheat series, where they overlap, are highly correlated and have similar coefficients of variation.

Calendar-year information on real wages is not available. However, the correlation between detrended Winchester harvest year wheat prices and detrended harvest year real wages for England[27] between 1675 and 1812 is fairly strong ($r = -0.8$).

A monthly temperature series for Central England is provided by Manley[28] from 1659 onward. Since it is likely that certain diseases are seasonal, it seemed appropriate to create four temperature variables, one for each season; average temperature in winter (average of January, February, and March), spring (average of April, May, and June), summer (average of July, August, and September), and autumn (average of October, November, and December). Two other temperature variables were included in an attempt to measure climatic variability. The first is the coefficient of variation for the first six months of the year and the second the coefficient of variation for the last six months of the year.

Wales-Smith[29] has published monthly rainfall figures from 1697 onward for Kew, a suburb of London. The rainfall variables are constructed in the same manner as the temperature variables, except that total seasonal values are used instead of averages.

[24] London deaths by cause 1670 to 1830 are from Marshall, *op. cit.* in footnote 2, unpaginated sheets. The series of typhus (spotted fever) deaths ends in 1728. The series of fever deaths used includes the categories of typhus (spotted fever), ague, and fever throughout. Fever probably includes malaria, influenza, typhoid fever, catarrh and similar diseases. Deaths from consumption probably represent deaths from tuberculosis and similar diseases. The series of deaths from apoplexy includes the categories of apoplexy and 'suddenly' which are probably vascular diseases. The series of deaths in infancy used is the same as Marshall's category of 'diseases incident to infancy' which consists primarily of deaths due to teething and convulsions. Convulsions are believed to be diarrhoea by C. Creighton, *A History of Epidemics in Britain from the Extinction of Plague to the Present Time* (Cambridge: University Press, 1894), vol. 2, p. 748. The series of deaths from diarrhoea used was calculated by adding together the categories of 'convulsions' and 'griping of the guts' as suggested by Creighton, pp. 747–748. Total deaths in England are from Wrigley and Schofield, *op. cit.* in footnote 3, pp. 498–501.

[25] Beveridge, *op. cit.* in footnote 5, pp. 81–84.

[26] B. R. Mitchell and P. Deane, *op. cit.* in footnote 6, p. 488.

[27] Wrigley and Schofield, *op. cit.* in footnote 3, pp. 643–644.

[28] Manley, *loc. cit.* in footnote 7, pp. 393–396.

[29] Wales-Smith, *loc. cit.* in footnote 8, pp. 357–359.

Table 2. *Means, standard deviations, and coefficients of variation of the proposed independent variables*

| | Mean of raw series | Standard deviation of raw series | Coefficient of variation | |
|---|---|---|---|---|
| | | | Raw series | Detrended series |
| Annual wheat price 1670 to 1830 | 45.2* | 24.1* | 0.533* | 0.216 |
| Central England average temperature in degrees Fahrenheit 1670 to 1830 | | | | |
| Winter (Jan.–Mar.) | 38.8 | 2.31 | 0.060 | 0.057 |
| Spring (Apr.–Jun.) | 52.0 | 1.50 | 0.029 | 0.025 |
| Summer (Jul.–Sep.) | 58.8 | 1.43 | 0.024 | 0.019 |
| Autumn (Oct.–Dec.) | 43.3 | 1.82 | 0.042 | 0.036 |
| Central England temperature coefficient of variation 1670 to 1830 | | | | |
| First half (Jan.–June) | 0.188 | 0.032 | 0.170 | 0.163 |
| Second half (July–Dec.) | 0.184 | 0.025 | 0.136 | 0.117 |
| Kew, total rainfall in inches 1697 to 1830 | | | | |
| Winter (Jan.–Mar.) | 4.74 | 1.71 | 0.361 | 0.343 |
| Spring (Apr.–Jun.) | 5.54 | 1.77 | 0.319 | 0.316 |
| Summer (Jul.–Sep.) | 6.71 | 2.22 | 0.331 | 0.298 |
| Autumn (Oct.–Dec.) | 6.61 | 2.03 | 0.307 | 0.288 |
| Kew, rainfall coefficient of variation 1697 to 1830 | | | | |
| First half (Jan.–June) | 0.533 | 0.195 | 0.366 | 0.341 |
| Second half (July–Dec.) | 0.509 | 0.190 | 0.373 | 0.375 |

* For the Winchester wheat price series from 1670 to 1817. See text for discussion.

## METHOD

The method is similar to that used by Lee[30] in his analysis of short-term variations in English vital rates, prices and weather. Since the analysis is concerned with annual fluctuations over time it is necessary to remove the secular trend from the series. This is done as before by dividing each data point, $x$, in a series by an eleven-year average of data points surrounding $x$.

It is likely that the dependent variable is affected not only by the impact of the contemporary, but also by previous values of the explanatory variables. A distributed-lag model is used to allow for effects on the dependent variable some years after the initial price and weather shock. A correction for second-order autoregressive disturbances was applied by using Cochrane and Orcutt's iterative procedure where the error process is defined as $e_t = s_1 e_{t-1} + s_2 e_{t-2} + u_t$ where $t$ is time, $e$ is the error term, $u$ is an independently distributed random variable, and $s$ is a coefficient. In a series with a moderate to large number of observations this correction should have little effect on the value of the regression coefficients, but should provide a better estimate of their significance.[31] Because of the nature of the detrending procedure, the estimated coefficients are elasticities.

In Table 3 we show the bivariate correlation matrix for the detrended independent

[30] Lee, *op. cit.* in footnote 9.
[31] A. C. Harvey, *The Economic Analysis of Time Series* (London: Philip Allen, 1981), pp. 189–199.

Table 3. *Bivariate correlations among the proposed independent variables 1675 to 1825 and 1702 to 1825*

| | Wheat price | Winter temp. | Spring temp. | Summer temp. | Autumn temp. | $CV_1$ temp. | $CV_2$ temp. | Winter rain | Spring rain | Summer rain | Autumn rain | $CV_1$ rain | $CV_2$ rain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat price | | −0.21 | −0.10 | −0.02 | 0.03 | 0.16 | −0.04 | | | | | | |
| Winter temp. | −0.19 | | 0.25 | 0.16 | 0.06 | −0.88 | 0.06 | | | | | | |
| Spring temp. | −0.13 | 0.26 | | 0.25 | 0.04 | 0.12 | 0.15 | | | | | | |
| Summer temp. | 0.03 | 0.15 | 0.31 | | 0.15 | −0.05 | 0.35 | | | | | | |
| Autumn temp. | −0.03 | 0.07 | 0.09 | 0.24 | | −0.05 | −0.82 | | | | | | |
| $CV_1$ temp. | 0.15 | −0.89 | 0.10 | −0.04 | −0.02 | | 0.01 | | | | | | |
| $CV_2$ temp. | 0.01 | 0.09 | 0.15 | 0.29 | −0.80 | −0.03 | | | | | | | |
| Winter rain | 0.13 | 0.06 | −0.03 | −0.06 | −0.04 | −0.06 | 0.01 | | | | | | |
| Spring rain | −0.02 | 0.03 | −0.17 | −0.12 | −0.13 | −0.15 | 0.08 | 0.03 | | | | | |
| Summer rain | 0.03 | 0.06 | 0.09 | −0.25 | −0.09 | −0.02 | −0.07 | 0.14 | 0.12 | | | | |
| Autumn rain | −0.08 | −0.06 | 0.03 | 0.09 | 0.01 | 0.07 | −0.03 | −0.13 | 0.03 | −0.09 | | | |
| $CV_1$ rain | −0.09 | 0.10 | −0.07 | −0.00 | −0.02 | −0.14 | 0.04 | −0.37 | 0.07 | −0.07 | −0.07 | | |
| $CV_2$ rain | −0.10 | 0.06 | 0.11 | 0.13 | −0.10 | −0.04 | 0.19 | −0.02 | −0.02 | −0.09 | −0.12 | 0.29 | |

*Notes:* The large lower left triangle of correlations is for the period 1702 to 1825. The small upper triangle of correlations is for the period 1675 to 1825. All variables have been detrended in the manner described in the text. Temperature is the average quarterly temperature. Rain is the total quarterly rainfall. $CV_1$ is the coefficient of variation of the first six months of the year. $CV_2$ is the coefficient of variation of the last six months of the year.

variables covering the periods 1675 to 1825 and 1702 to 1825. The latter period includes the rainfall variables. All the bivariate correlations are very low, except for winter temperature and first half variability, and autumn temperature and second half variability. This is an interesting finding in itself which implies that the colder the winter or autumn the greater the month-to-month temperature variability.[32] Because of this collinearity, the two measures of variability are not included in the regression analyses. However, it should be kept in mind when interpreting the results that winter temperature is virtually interchangeable with first half variability and autumn temperature is virtually interchangeable with second half variability. The two measures of rainfall variability were also excluded from the regression analyses since they were found to have no significant explanatory power.

Three regressions were run: deaths by age as a function of wheat prices, average quarterly temperatures and quarterly rainfall from 1733 to 1825; deaths by cause as a function of wheat prices and average quarterly temperature from 1675 to 1825; and deaths by cause as a function of wheat prices, average quarterly temperature and quarterly rainfall from 1706 to 1825. The price variable is distributively lagged five years and each weather variable three years. Extending the lag length beyond these values generally provided no significant additional information.

The equations are shown below. Each variable has been detrended in the manner described above. $P$ represents calendar-year wheat price, $T_1$ average winter temperature, $T_2$ average spring temperature, $T_3$ average summer temperature, $T_4$ average autumn temperature, $R_1$ winter rainfall, $R_2$ spring rainfall, $R_3$ summer rainfall, and $R_4$ autumn rainfall. The regression coefficients are represented by $b_j$. The constant is $a$, the error term is $e$, and $t$ is time.

The period for Equation 1 is 1733 to 1825. $D_x$ represents annual London deaths in age group $x$. The age groups are: 0–1, 2–4, 5–9, 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, 80–89, and 90 and over. For age group 0–1 only, births[33] distributively lagged five years are also included in the regression equation since variations in deaths in this age group will be affected by variations in births.

$$D_{x,t} = a_x + \sum_{k=0}^{4} b_{1,x,k} P_{t-k} + \sum_{k=0}^{2} b_{2,x,k} T_{1,t-k} + \sum_{k=0}^{2} b_{3,x,k} T_{2,t-k}$$

$$+ \sum_{k=0}^{2} b_{4,x,k} T_{3,t-k} + \sum_{k=0}^{2} b_{5,x,k} T_{4,t-k} + \sum_{k=0}^{2} b_{6,x,k} R_{1,t-k}$$

$$+ \sum_{k=0}^{2} b_{7,x,k} R_{2,t-k} + \sum_{k=0}^{2} b_{8,x,k} R_{3,t-k} + \sum_{k=0}^{2} b_{9,x,k} R_{4,t-k} + e_{x,t}. \quad (1)$$

The next set of regressions are similar except that deaths by cause are the dependent variables. The period for Equation 2 is 1675 to 1825, for Equation 3 1706 to 1825. $D_c$ represents annual London deaths by cause $c$ for the following causes: typhus, smallpox, fever, consumption, dropsy, apoplexy, old age, infancy, and diarrhoea. Regressions are also run for total deaths in London and in England. Because the period for typhus deaths is 1675 to 1723, the regression for typhus deaths is not run for Equation 3. Births distributively lagged five years are included in the regression equations for infancy deaths and deaths from diarrhoea.

[32] Increased day-to-day and month-to-month climatic variability is associated with increased mortality. See Tromp, *op. cit.* in footnote 12.

[33] The London birth series 1670 to 1830 is from the London Bills of Mortality and Marshall, *op. cit.* in footnote 2, pp. 63, 67, and 70–71.

$$D_{c,t} = a_c + \sum_{k=0}^{4} b_{1,c,k} P_{t-k} + \sum_{k=0}^{2} b_{2,c,k} T_{1,t-k} + \sum_{k=0}^{2} b_{3,c,k} T_{2,t-k} + \sum_{k=0}^{2} b_{4,c,k} T_{3,t-k} + \sum_{k=0}^{2} b_{5,c,k} T_{4,t-k} + e_{c,t}. \quad (2)$$

$$D_{c,t} = a_c + \sum_{k=0}^{4} b_{1,c,k} P_{t-k} + \sum_{k=0}^{2} b_{2,c,k} T_{1,t-k} + \sum_{k=0}^{2} b_{3,c,k} T_{2,t-k} + \sum_{k=0}^{2} b_{4,c,k} T_{3,t-k} + \sum_{k=0}^{2} b_{5,c,k} T_{4,t-k} + \sum_{k=0}^{2} b_{6,c,k} R_{1,t-k} + \sum_{k=0}^{2} b_{7,c,k} R_{2,t-k} + \sum_{k=0}^{2} b_{8,c,k} R_{3,t-k} + \sum_{k=0}^{2} b_{9,c,k} R_{4,t-k} + e_{c,t}. \quad (3)$$

The regression coefficients for Equations 1, 2 and 3 are shown in Appendix Tables 1, 2 and 3.

## DEATHS BY AGE GROUP

The results of the regressions of deaths by age group on prices, temperature, and rainfall (Equation 1) are shown graphically in Figure 1. $\beta$-coefficients are plotted in order to display clearly the relative importance of each independent variable. For example, an increase of one standard deviation in summer temperature at lag 0 results in an increase of four-tenths of a standard deviation in deaths in the age group 60 to 69 at lag 0, followed by a very small decrease in deaths a year later, and then in an increase of about two-tenths of a standard deviation in deaths two years after the initial shock. Staying with age group 60 to 69 and assuming an increase of one standard deviation in each independent variable at lag 0, it is clear that the greatest effect on deaths in this age group at lag 0 is that of summer temperature variations, followed by winter temperature, spring rainfall, prices, spring temperature, and so on.

Looking at each independent variable separately, Figure 1 shows that an increase in prices increases deaths in all age groups at lag 0. This is followed by a large compensating decline in deaths among all age groups a year later, and then a small increase in all age groups two years after the initial price shock. The increase in deaths at lag 0 between ages 10 and 39 is probably due to the effects of in-migration during years of harvest failure. The second peak may be a result of nutritional effects on older persons.

The most striking result is the tremendous and lasting impact of cold winters on the number of deaths in the older age groups. An increase in summer temperature significantly increases deaths in the middle and old age groups. These results are consistent with Lee's analysis of deaths in England.[34] Somewhat surprisingly, a decrease in spring rainfall results in a significant increase in deaths in most age groups. Waddy has shown that absolute humidity is an important factor in the spread of airborne disease.[35] He notes that cold dry weather facilitates the spread of airborne infection in England. Figure 1 shows that variations in spring temperature, autumn temperature, winter rainfall, summer rainfall, and autumn rainfall have little effect on deaths in most age groups.

[34] Lee, *op. cit.* in footnote 9, p. 393.

[35] B. B. Waddy, 'Climate and respiratory infections', *The Lancet* (4 Oct. 1952), pp. 674–677.

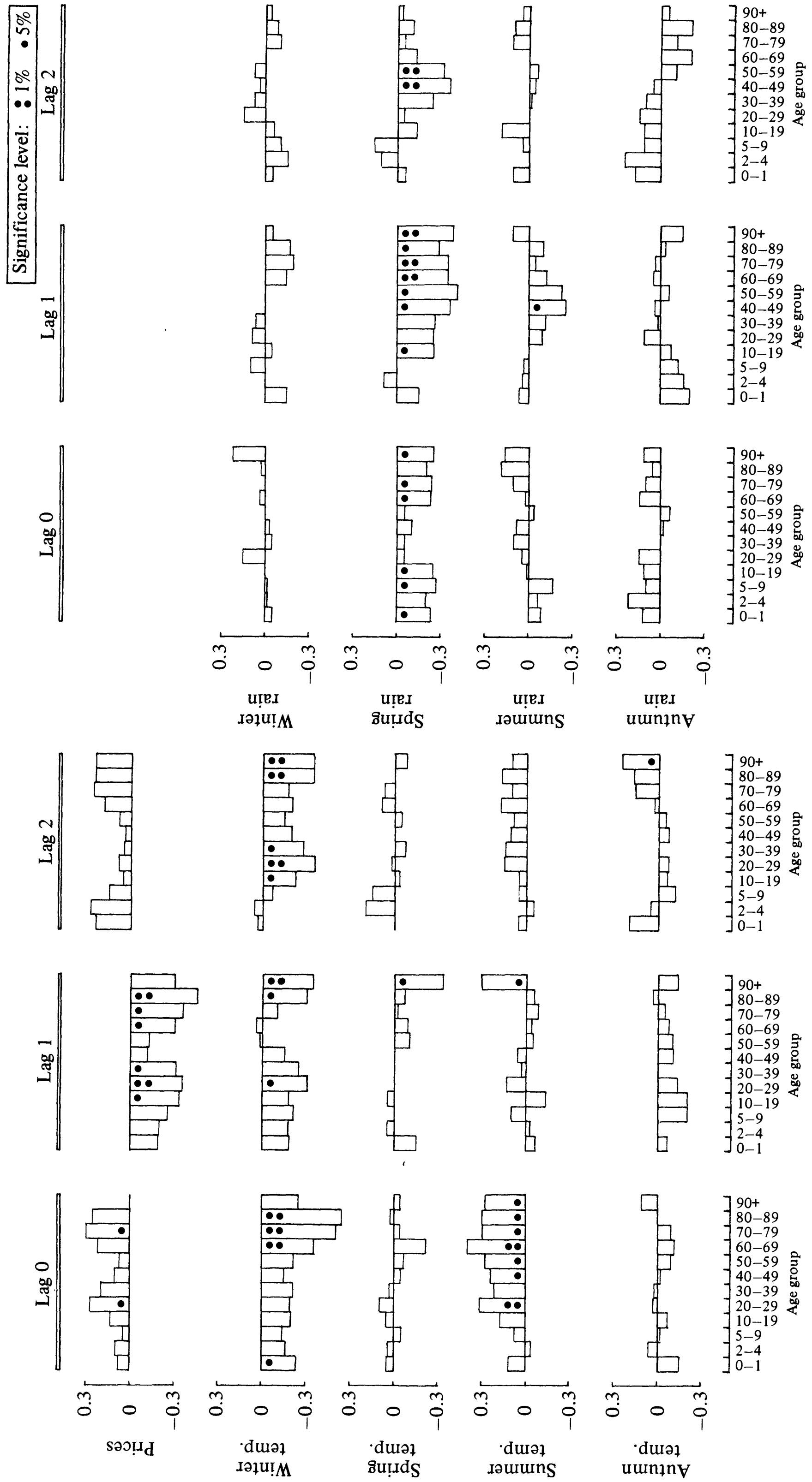


Fig. 1. Response of deaths by age group to increases in prices, temperature and rainfall in London 1733 to 1825. $\beta$-coefficients are plotted from Appendix Table 1.

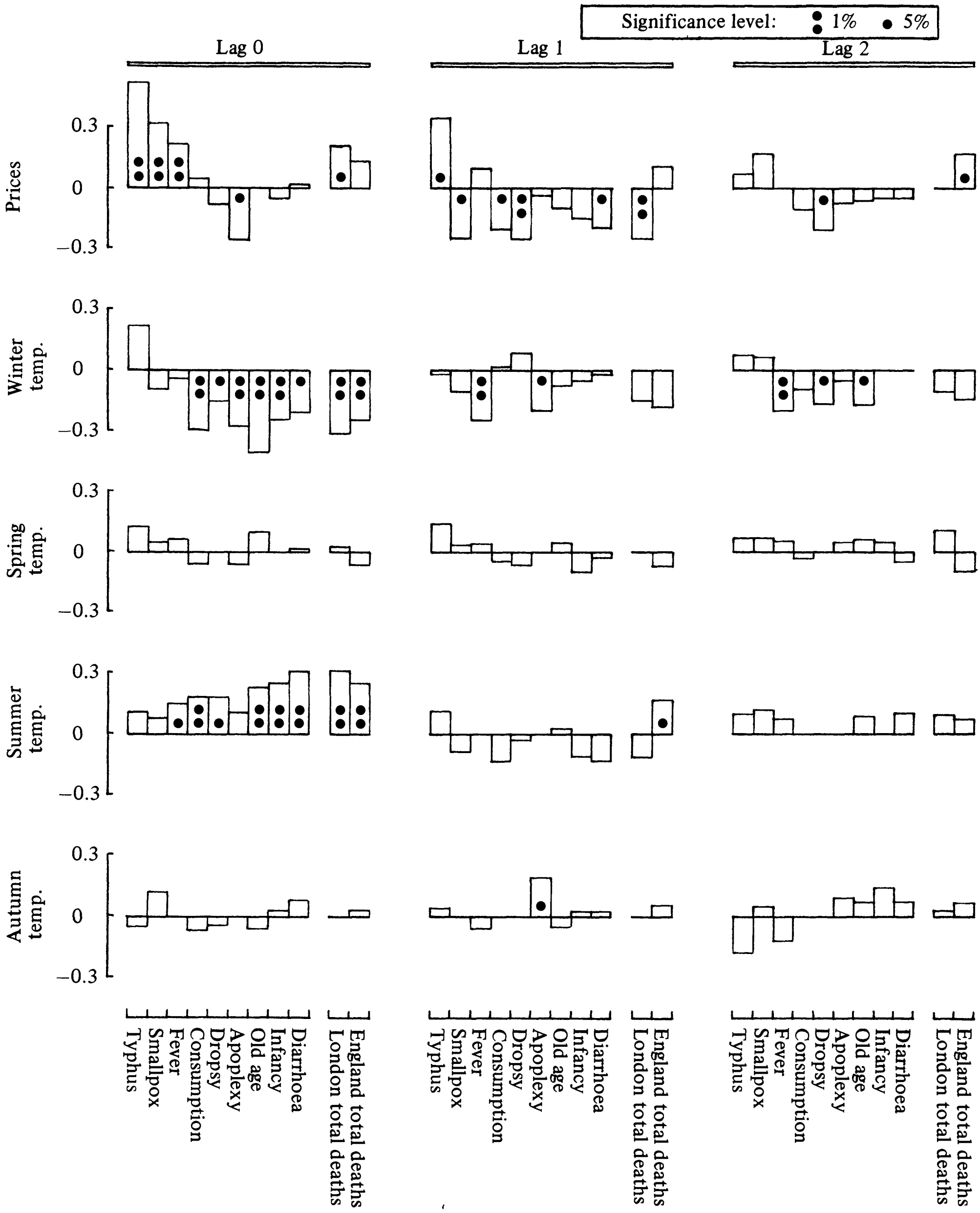


Fig. 2. Response of deaths by cause to increases in prices and temperature in London 1675 to 1825. $\beta$-coefficients are plotted from Appendix Table 2.

## DEATHS BY CAUSE

In Figure 2 we show the response of deaths from different causes to increases in prices and temperature between 1675 and 1825. The results of regressions of deaths by cause on prices, temperature and rainfall variables during the period 1706 to 1825 are shown in Figure 3. Looking at Figure 2 it is apparent that an increase in prices at lag 0 is associated with a significant and large increase in deaths from epidemic diseases (typhus,

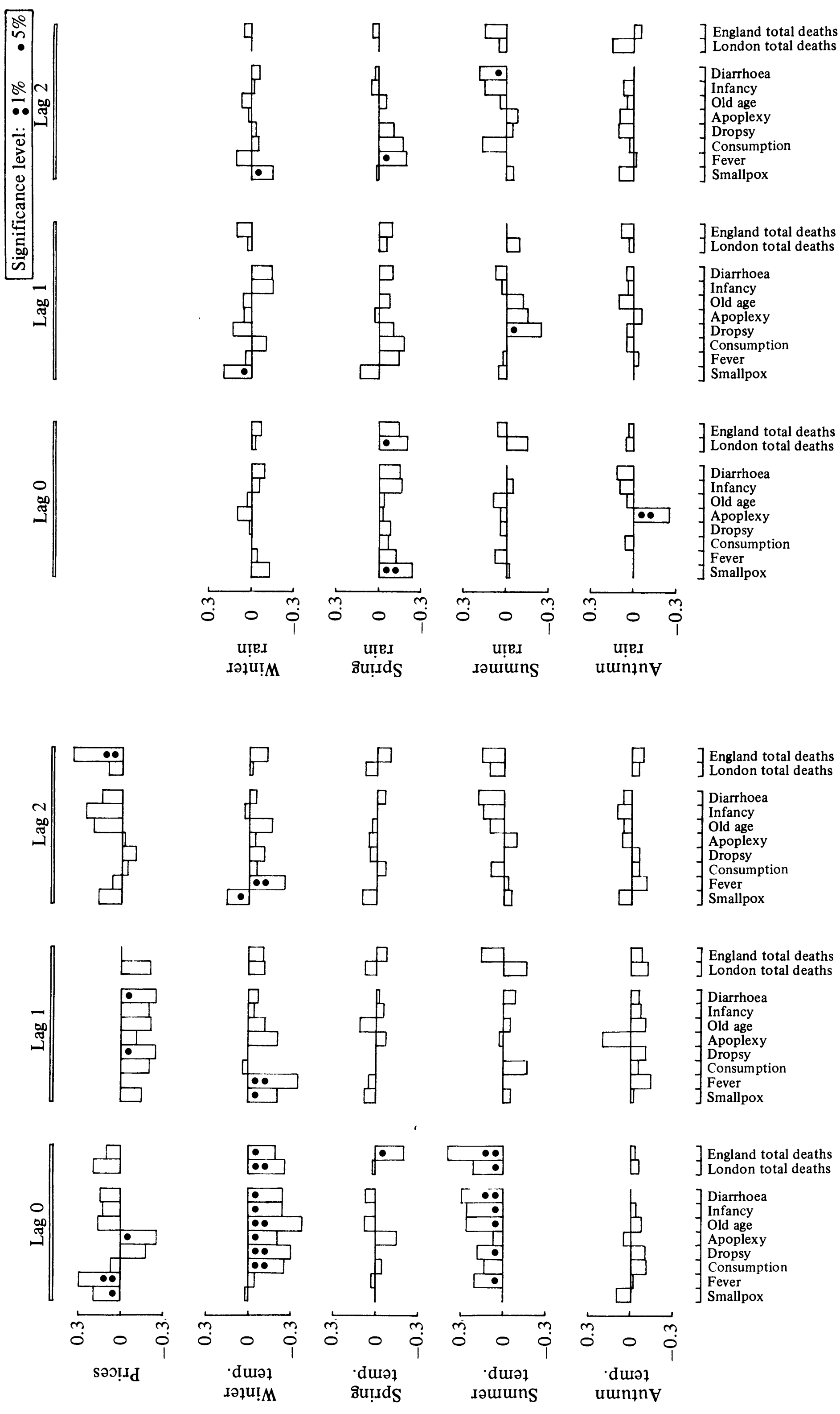


Fig. 3. Response of deaths by cause to increases in prices, temperature and rainfall in London 1706 to 1825. $\beta$-coefficients are plotted from Appendix Table 3.

smallpox and fever). Endemic diseases (consumption, dropsy, apoplexy, old age, infancy, and diarrhoea) are less affected by price changes but increase significantly when winter temperatures decrease and when summer temperatures increase. Deaths from old age, consumption, and apoplexy are the most responsive to decreases in winter temperature while those from diarrhoea, infancy and old age are most responsive to increases in summer temperature. Spring and autumn temperature and quarterly variations in rainfall seem to have little impact on deaths by cause.

Increases in prices, decreases in winter temperatures, and increases in summer temperatures tend to increase total deaths in London. The variables have the same impact on total deaths in England, but the lag structure is somewhat different.

## CONCLUSIONS

An increase in prices is clearly associated with an increase in deaths among Londoners in the middle and older age groups. It is likely that the increase in deaths in the middle age groups is a result of migration into the city during poor harvest years. It is possible that the increase in deaths may have occurred mainly among the in-migrants who, having left a relatively pristine rural environment, were suddenly exposed to London's myriad pathogenic organisms. On the other hand, perhaps the in-migrants introduced Londoners to some new and deadly micro-organisms. Available data cannot solve this problem. In any case the probable increase in the frequency of interaction of the populace of London due to in-migration as a result of poor harvests would tend to increase the number of deaths resulting from infectious diseases.

The significant increase in deaths in the older age groups is more probably a result of diseases associated with nutritional deficiencies since migration studies generally show little migration among the elderly. Increased exposure to infectious diseases spawned by increased population interaction as a result of in-migration in other age groups during a poor harvest might also tend to increase deaths at older ages.

Possibly the most significant finding in this analysis is that epidemic diseases are strongly associated with price increases and that endemic diseases are strongly associated with decreased winter temperature and increased summer temperature. One might speculate on the long-term implications for mortality decline in light of these results. The general increase in crop yields, transport, market integration, and the introduction of the potato would lead to a decrease in the variability of harvests and a decrease in the frequency of catastrophic crop failures leading to a decline in deaths from typhus, smallpox, and fevers. The gradual global warming beginning around the end of the seventeenth century[36] and improvements in indoor heating technology would tend to decrease the impact of cold winters on mortality. Since deaths due to increased summer temperature are mainly a result of poor sanitation, the development of public health programmes and improvements in water supplies and refuse and sewage disposal would lessen the impact of hot summers on the death rate.

[36] P. R. Galloway, 'Long term fluctuations in climate and population in the pre-industrial era'. Program in Population Research Working Paper No. 14, University of California, Berkeley, 1984.

Appendix Table 1. *Regressions of deaths by age on lagged wheat prices and lagged climatic variables in London 1733 to 1825*

| | Deaths by Age Group | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–1 | 2–4 | 5–9 | 10–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70–79 | 80–89 | > 89 |
| $R^2$... | 0.58 | 0.40 | 0.38 | 0.53 | 0.46 | 0.23 | 0.21 | 0.03 | 0.43 | 0.55 | 0.51 | 0.36 |
| Wheat price | | | | | | | | | | | | |
| Lag 0 | 0.08 | 0.10 | 0.04 | 0.13 | 0.27 b | 0.19 | 0.11 | 0.07 | 0.22 d | 0.29 b | 0.26 c | −0.01 |
| Lag 1 | −0.18 | −0.19 | −0.26 d | −0.33 b | −0.35 a | −0.31 b | −0.12 | −0.13 | −0.30 b | −0.36 b | −0.45 a | −0.29 c |
| Lag 2 | 0.23 d | 0.28 | 0.15 | 0.05 | 0.09 | 0.05 | 0.04 | 0.08 | 0.18 | 0.26 c | 0.24 c | 0.24 |
| Lag 3 | −0.31 b | −0.34 c | −0.20 | −0.29 b | −0.00 | 0.03 | −0.01 | −0.05 | −0.05 | −0.14 | −0.21 d | −0.26 d |
| Lag 4 | 0.01 | 0.05 | 0.04 | −0.07 | −0.23 c | −0.31 b | −0.23 c | −0.23 c | −0.13 | −0.08 | −0.03 | 0.36 b |
| Winter temp. | | | | | | | | | | | | |
| Lag 0 | −0.23 b | −0.17 d | −0.14 | −0.20 c | −0.19 c | −0.21 c | −0.15 d | −0.22 c | −0.36 a | −0.50 a | −0.54 a | −0.25 c |
| Lag 1 | −0.18 c | −0.17 d | −0.21 c | −0.18 c | −0.31 b | −0.24 c | −0.16 | 0.02 | 0.04 | −0.10 | −0.29 b | −0.33 a |
| Lag 2 | 0.03 | 0.06 | −0.08 | −0.22 b | −0.35 a | −0.28 b | −0.19 c | −0.15 d | −0.19 c | −0.17 c | −0.34 a | −0.34 a |
| Spring temp. | | | | | | | | | | | | |
| Lag 0 | 0.05 | 0.04 | −0.05 | 0.05 | 0.10 | 0.03 | −0.04 | −0.07 | −0.22 c | −0.03 | 0.02 | −0.03 |
| Lag 1 | −0.14 | 0.04 | 0.01 | 0.05 | −0.00 | 0.00 | −0.01 | −0.10 | −0.09 | −0.02 | −0.07 | −0.33 b |
| Lag 2 | 0.01 | 0.20 d | 0.16 | −0.03 | 0.02 | −0.08 | 0.00 | −0.04 | 0.09 | 0.07 | 0.00 | −0.08 |
| Summer temp. | | | | | | | | | | | | |
| Lag 0 | 0.12 | −0.03 | 0.08 | 0.18 d | 0.32 a | 0.22 d | 0.24 b | 0.28 b | 0.40 a | 0.29 b | 0.30 b | 0.27 b |
| Lag 1 | −0.07 | −0.03 | 0.11 | −0.13 | 0.13 | 0.03 | 0.06 | −0.04 | −0.03 | −0.08 | −0.05 | 0.32 b |
| Lag 2 | 0.05 | −0.05 | 0.05 | 0.05 | 0.15 d | 0.14 | 0.11 | 0.09 | 0.18 d | 0.10 | 0.17 d | 0.10 |
| Autumn temp. | | | | | | | | | | | | |
| Lag 0 | −0.16 d | 0.07 | −0.02 | −0.07 | 0.03 | 0.02 | −0.02 | −0.09 | −0.11 | −0.09 | 0.01 | 0.12 |
| Lag 1 | −0.07 | 0.00 | −0.19 d | −0.20 c | −0.13 | −0.00 | −0.10 | −0.09 | −0.07 | −0.04 | 0.03 | −0.13 |
| Lag 2 | 0.20 c | 0.05 | −0.11 | −0.05 | −0.06 | −0.01 | −0.06 | −0.04 | 0.03 | 0.17 d | 0.18 c | 0.24 b |

Appendix Table 1 continued overleaf

## Appendix Table 1 (*cont.*)

| | Deaths by Age Group | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–1 | 2–4 | 5–9 | 10–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70–79 | 80–89 | > 89 |
| $R^2$... | 0.58 | 0.40 | 0.38 | 0.53 | 0.46 | 0.23 | 0.21 | 0.03 | 0.43 | 0.55 | 0.51 | 0.36 |
| Winter rain | | | | | | | | | | | | |
| Lag 0 | −0.06 | −0.02 | −0.02 | 0.00 | 0.15 d | −0.06 | −0.03 | 0.01 | 0.04 | −0.01 | 0.03 | 0.23 c |
| Lag 1 | −0.15 d | −0.00 | 0.10 | −0.04 | 0.09 | 0.07 | −0.01 | 0.01 | −0.14 | −0.19 c | −0.17 d | −0.04 |
| Lag 2 | −0.06 | −0.14 | −0.10 | −0.06 | 0.14 d | 0.08 | 0.04 | 0.08 | −0.01 | −0.10 | −0.08 | −0.04 |
| Spring rain | | | | | | | | | | | | |
| Lag 0 | −0.23 b | −0.20 c | −0.28 b | −0.26 b | −0.05 | −0.05 | −0.10 | −0.05 | −0.23 b | −0.24 b | −0.21 c | −0.25 b |
| Lag 1 | −0.15 | 0.09 | −0.01 | −0.25 b | −0.24 c | −0.26 c | −0.37 b | −0.41 b | −0.34 a | −0.34 a | −0.28 b | −0.38 a |
| Lag 2 | −0.06 | 0.12 | 0.17 d | −0.13 d | −0.04 | −0.23 c | −0.37 a | −0.32 a | −0.13 | −0.04 | −0.11 | −0.03 |
| Summer rain | | | | | | | | | | | | |
| Lag 0 | −0.08 | −0.06 | −0.18 d | 0.02 | 0.06 | 0.10 | 0.08 | −0.03 | 0.02 | 0.10 | 0.18 c | 0.16 d |
| Lag 1 | 0.07 | 0.04 | 0.03 | −0.01 | −0.09 | −0.11 | −0.25 b | −0.22 d | −0.12 | −0.04 | −0.09 | 0.12 |
| Lag 2 | 0.12 | 0.01 | 0.06 | 0.19 c | −0.01 | −0.02 | −0.04 | −0.06 | −0.00 | 0.13 d | 0.10 | 0.04 |
| Autumn rain | | | | | | | | | | | | |
| Lag 0 | 0.12 | 0.22 c | 0.10 | 0.11 | 0.14 d | 0.01 | −0.02 | −0.07 | 0.14 | 0.10 | 0.05 | 0.12 |
| Lag 1 | −0.19 c | −0.16 d | −0.12 | −0.08 | 0.12 | 0.02 | 0.04 | −0.06 | 0.06 | 0.04 | −0.03 | −0.14 |
| Lag 2 | 0.18 d | 0.25 c | 0.12 | 0.12 | 0.16 d | 0.11 | 0.05 | −0.10 | −0.21 d | −0.11 | −0.21 c | −0.06 |
| Births | | | | | | | | | | | | |
| Lag 0 | 0.18 d | | | | | | | | | | | |
| Lag 1 | 0.11 | | | | | | | | | | | |
| Lag 2 | 0.15 d | | | | | | | | | | | |
| Lag 3 | −0.10 | | | | | | | | | | | |
| Lag 4 | −0.27 b | | | | | | | | | | | |

*Notes:* All variables have been detrended in the manner described in the text. $\beta$-coefficients are shown. The regressions have been corrected for second-order autoregressive disturbances by using Cochrane and Orcutt's iterative procedure. $R^2$ has been calculated for the untransformed variables. The $t$ statistic significance levels are indicated as follows: a is 1%, b is 5%, c is 10%, and d is 20%.

Appendix Table 2. *Regressions of deaths by cause on lagged wheat prices and lagged climatic variables in London 1675 to 1825*

| | Death by Cause | | | | | | | | | London total | England total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Typhus | Smallpox | Fever | Consumption | Dropsy | Apoplexy | Old Age | Infancy | Diarrhoea | | |
| $R^2$... | 0.66 | 0.26 | 0.29 | 0.27 | 0.20 | 0.17 | 0.24 | 0.22 | 0.27 | 0.30 | 0.25 |
| Wheat price | | | | | | | | | | | |
| Lag 0 | 0.52 a | 0.32 a | 0.22 a | 0.04 | −0.08 | −0.24 b | 0.01 | −0.05 | 0.02 | 0.21 b | 0.13 d |
| Lag 1 | 0.35 b | −0.24 b | 0.10 | −0.20 b | −0.24 a | −0.03 | −0.10 | −0.15 d | −0.19 b | −0.24 a | 0.11 d |
| Lag 2 | 0.07 | 0.17 d | 0.00 | −0.11 d | −0.21 b | −0.08 | −0.07 | −0.05 | −0.05 | 0.01 | 0.17 b |
| Lag 3 | −0.02 | −0.20 c | −0.04 | −0.20 b | 0.03 | 0.08 | 0.01 | −0.09 | −0.16 c | −0.14 d | −0.06 |
| Lag 4 | −0.06 | 0.07 | −0.07 | −0.15 c | −0.13 d | 0.09 | −0.06 | −0.06 | −0.06 | −0.07 | −0.04 |
| Winter temp. | | | | | | | | | | | |
| Lag 0 | 0.22 d | −0.09 | −0.04 | −0.29 a | −0.16 b | −0.27 a | −0.41 a | −0.24 a | −0.21 b | −0.32 a | −0.25 a |
| Lag 1 | −0.02 | −0.11 d | −0.24 a | 0.02 | 0.09 | −0.19 b | −0.08 | −0.04 | −0.02 | −0.14 d | −0.18 c |
| Lag 2 | 0.07 | 0.06 | −0.20 a | −0.09 | −0.17 b | −0.05 | −0.17 b | −0.01 | 0.01 | −0.11 d | −0.14 c |
| Spring temp. | | | | | | | | | | | |
| Lag 0 | 0.13 | 0.05 | 0.07 | −0.06 | −0.00 | −0.06 | 0.10 | 0.00 | 0.02 | 0.03 | −0.07 |
| Lag 1 | 0.14 | 0.04 | 0.05 | −0.05 | −0.07 | −0.00 | 0.05 | −0.10 | −0.03 | 0.01 | −0.07 |
| Lag 2 | 0.07 | 0.07 | 0.05 | −0.03 | −0.01 | 0.04 | 0.06 | 0.04 | −0.05 | 0.11 d | −0.09 |
| Summer temp. | | | | | | | | | | | |
| Lag 0 | 0.11 | 0.08 | 0.14 b | 0.18 a | 0.18 b | 0.11 d | 0.23 a | 0.25 a | 0.31 a | 0.32 a | 0.25 a |
| Lag 1 | 0.12 | −0.08 | 0.01 | −0.13 c | −0.03 | −0.01 | 0.03 | −0.11 | −0.13 d | −0.12 d | 0.17 b |
| Lag 2 | 0.10 | 0.12 c | 0.07 | 0.01 | 0.00 | −0.01 | 0.09 | −0.00 | 0.11 | 0.10 | 0.08 |
| Autumn temp. | | | | | | | | | | | |
| Lag 0 | −0.05 | 0.12 c | 0.01 | −0.07 | −0.04 | 0.01 | −0.06 | 0.03 | 0.08 | −0.01 | 0.04 |
| Lag 1 | 0.04 | −0.01 | −0.06 | 0.00 | −0.01 | 0.19 b | −0.05 | 0.02 | 0.02 | −0.00 | 0.05 |
| Lag 2 | −0.17 | 0.05 | −0.12 d | −0.01 | 0.01 | 0.09 | 0.07 | 0.14 d | 0.07 | 0.03 | 0.06 |
| Births | | | | | | | | | | | |
| Lag 0 | | | | | | | | 0.11 | 0.09 | | |
| Lag 1 | | | | | | | | 0.07 | 0.10 | | |
| Lag 2 | | | | | | | | −0.02 | −0.11 d | | |
| Lag 3 | | | | | | | | 0.07 | 0.07 | | |
| Lag 4 | | | | | | | | 0.02 | 0.13 d | | |

*Notes:* The period for typhus is 1675 to 1723. All variables have been detrended in the manner described in the text. $\beta$-coefficients are shown. The regressions have been corrected for second-order autoregressive disturbances by using Cochrane and Orcutt's iterative procedure. $R^2$ has been calculated for the untransformed variables. The $t$ statistic significance levels are indicated as follows: a is 1%, b is 5%, c is 10%, and d is 20%.

Appendix Table 3. *Regressions of deaths by cause on lagged wheat prices and lagged climatic variables in London 1706 to 1825*

| | Death by Cause | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Smallpox | Fever | Consumption | Dropsy | Apoplexy | Old Age | Infancy | Diarrhoea | London Total | England Total |
| $R^2$... | 0.39 | 0.32 | 0.38 | 0.44 | 0.30 | 0.29 | 0.48 | 0.45 | 0.45 | 0.38 |
| Wheat price | | | | | | | | | | |
| Lag 0 | 0.19 b | 0.29 a | 0.07 | −0.18 d | −0.26 b | 0.17 d | 0.13 | 0.15 | 0.19 c | 0.10 |
| Lag 1 | −0.15 | 0.01 | −0.20 c | −0.24 b | −0.11 | −0.22 c | −0.20 d | −0.25 b | −0.22 c | −0.01 |
| Lag 2 | 0.17 | 0.07 | −0.04 | −0.10 | −0.02 | 0.19 d | 0.24 c | 0.14 | 0.09 | 0.34 a |
| Lag 3 | −0.21 d | −0.00 | −0.26 b | −0.17 d | 0.02 | −0.03 | −0.25 b | −0.17 d | −0.20 c | −0.06 |
| Lag 4 | 0.02 | −0.05 | −0.10 | 0.00 | 0.07 | 0.05 | 0.06 | −0.07 | −0.03 | −0.02 |
| Winter temp. | | | | | | | | | | |
| Lag 0 | 0.02 | −0.04 | −0.26 a | −0.30 a | −0.21 b | −0.38 a | −0.24 b | −0.24 b | −0.26 a | −0.19 b |
| Lag 1 | −0.20 b | −0.36 a | 0.04 | 0.01 | −0.21 c | −0.12 | −0.04 | −0.07 | −0.12 | −0.11 |
| Lag 2 | 0.16 b | −0.24 a | −0.06 | −0.11 | −0.04 | −0.17 d | 0.03 | −0.04 | −0.02 | −0.12 d |
| Spring temp. | | | | | | | | | | |
| Lag 0 | 0.00 | 0.03 | −0.04 | −0.01 | −0.16 d | 0.08 | 0.00 | 0.07 | 0.02 | −0.19 b |
| Lag 1 | 0.08 | 0.05 | −0.01 | −0.01 | −0.07 | 0.11 | −0.05 | −0.02 | 0.08 | −0.07 |
| Lag 2 | 0.10 d | −0.01 | −0.06 | 0.04 | 0.05 | 0.03 | 0.01 | −0.06 | 0.08 | −0.09 |
| Summer temp. | | | | | | | | | | |
| Lag 0 | −0.00 | 0.21 b | 0.13 d | 0.19 b | 0.07 | 0.26 b | 0.26 b | 0.29 a | 0.22 b | 0.38 a |
| Lag 1 | −0.06 | −0.01 | −0.18 c | 0.00 | 0.03 | −0.04 | 0.01 | −0.08 | −0.17 c | 0.17 c |
| Lag 2 | −0.06 | −0.03 | 0.09 | 0.00 | −0.08 | 0.10 | 0.14 d | 0.18 c | 0.11 | 0.16 c |
| Autumn temp. | | | | | | | | | | |
| Lag 0 | 0.10 d | −0.02 | −0.11 d | −0.10 | 0.05 | −0.08 | −0.03 | −0.00 | −0.06 | −0.03 |
| Lag 1 | −0.02 | −0.14 | −0.07 | −0.11 | 0.20 c | −0.11 | −0.08 | −0.07 | −0.12 | −0.08 |
| Lag 2 | 0.09 d | −0.11 | −0.05 | −0.05 | 0.07 | 0.06 | 0.10 | 0.07 | −0.05 | −0.08 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Winter rain | | | | | | | | | | |
| Lag 0 | −0.13 c | −0.04 | −0.00 | 0.02 | 0.10 | 0.04 | −0.05 | −0.08 | −0.03 | −0.07 |
| Lag 1 | 0.19 b | 0.03 | −0.10 | 0.13 d | 0.05 | 0.06 | −0.15 d | −0.14 d | 0.03 | 0.11 |
| Lag 2 | −0.14 b | 0.12 d | −0.05 | −0.03 | 0.02 | 0.07 | −0.02 | −0.06 | −0.01 | 0.05 |
| Spring rain | | | | | | | | | | |
| Lag 0 | −0.23 a | −0.12 d | −0.07 | −0.09 | −0.03 | −0.04 | −0.17 c | −0.15 d | −0.20 b | −0.14 c |
| Lag 1 | 0.13 d | −0.13 | −0.18 d | −0.10 | 0.03 | −0.07 | 0.00 | −0.09 | −0.05 | −0.09 |
| Lag 2 | 0.02 | −0.19 b | −0.17 c | −0.11 | 0.00 | −0.05 | 0.06 | 0.03 | 0.00 | 0.04 |
| Summer rain | | | | | | | | | | |
| Lag 0 | −0.02 | 0.08 | −0.01 | 0.04 | 0.04 | 0.09 | −0.04 | 0.00 | −0.14 d | 0.07 |
| Lag 1 | 0.05 | 0.02 | 0.01 | −0.24 b | −0.16 d | −0.12 | 0.04 | 0.08 | −0.09 | −0.01 |
| Lag 2 | −0.05 | −0.01 | 0.17 c | −0.04 | −0.08 | 0.04 | 0.15 d | 0.18 b | 0.05 | 0.15 c |
| Autumn rain | | | | | | | | | | |
| Lag 0 | −0.01 | −0.00 | 0.06 | −0.00 | −0.26 a | 0.04 | 0.10 | 0.12 | 0.05 | 0.03 |
| Lag 1 | −0.01 | −0.03 | 0.05 | 0.05 | −0.06 | 0.11 | 0.03 | 0.05 | 0.03 | 0.09 |
| Lag 2 | 0.11 d | −0.02 | 0.03 | 0.12 | 0.10 | 0.04 | 0.07 | 0.00 | 0.15 d | −0.05 |
| Births | | | | | | | | | | |
| Lag 0 | | | | | | | 0.26 b | 0.20 b | | |
| Lag 1 | | | | | | | 0.20 c | 0.16 d | | |
| Lag 2 | | | | | | | 0.04 | −0.04 | | |
| Lag 3 | | | | | | | 0.06 | 0.05 | | |
| Lag 4 | | | | | | | −0.11 | −0.02 | | |

*Notes:* All variables have been detrended in the manner described in the text. $\beta$-coefficients are shown. The regressions have been corrected for second-order autoregressive disturbances by using Cochrane and Orcutt's iterative procedure. $R^2$ has been calculated for the untransformed variables. The $t$ statistic significance levels are indicated as follows: a is 1%, b is 5%, c is 10%, and d is 20%.