SECULAR CHANGES IN THE SHORT-TERM PREVENTIVE, POSITIVE, AND TEMPERATURE CHECKS TO POPULATION GROWTH IN EUROPE, 1460 TO 1909

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Abstract. Annual variations in births, marriages, deaths, grain prices, and quarterly temperature series in England, France, Prussia, and Sweden are analyzed using a distributed lag model. The results provide support for the existence of the short-term preventive, positive and temperature checks to population growth. Decreases in fertility and nuptiality are generally associated with increases in grain prices. Increases in mortality appear to be associated with high grain prices, cold winters and hot summers. Changes in these responses over time are examined within the context of economic development.

'The causes of a high mortality are various; but the greater number of known causes may be referred to five heads: 1) excessive cold or heat; 2) privation of food; 3) effluvial poisons generated in marshes, foul prisons, camps, cities; and epidemic diseases, such as typhus, plague, small pox, and other zymotic diseases; 4) mechanical and chemical injuries; 5) spontaneous disorders to which the structure of the human organization renders it liable.' – Farr (1846, p. 164).

'...a foresight of the difficulties attending the rearing of a family acts as a preventive check, and the actual distresses of some of the lower classes, by which they are disabled from giving the proper food and attention to their children, acts as a positive check to the natural increase of population.' – Malthus (1798, Chapter 4).

Introduction

One measure of development may be reflected in the ability of a society to successfully insulate itself from the vagaries of exogenous environmental shocks. For example, in modern industrialized countries an annual increase in the consumer price index or an annual reduction in the real wage probably has little impact on overall annual mortality. Institutional programs (especially in northern and central

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European countries) are generally thought to be sufficient to prevent deaths of the poor from possible starvation and malnutrition resulting from an annual increase in prices or overall reduction in the real wage. On the other hand, the impact of annual changes in the standard of living on annual variations in fertility in developed countries can be substantial. A decrease in the annual real wage may cause couples to end or postpone reproduction. However a decrease in the annual real wage might reduce the opportunity costs of working wives and lead to an increase in fertility.

One purpose of this paper is to examine how annual changes in exogenous forces like food prices and seasonal temperatures affect demographic behavior and how the magnitude of these short-term effects changes over time in preindustrial England, France, Prussia and Sweden. Mortality responses to annual fluctuations in the economy (the short-term positive check) and the weather (the short-term temperature-mortality check) should diminish according to some measure of economic development. In other words, as a country's living standard rises, insulation from these kinds of exogenous shocks should also increase. We will also examine annual fertility responses to annual variations in the standard of living (the short-term preventive check) and weather (the short-term temperature-fertility check). The impact of annual fluctuations in living standards on annual variations in nuptiality will also be analyzed.

Another purpose of this paper is somewhat more technical. Examination of the relationship between short-run fluctuations in vital events and the economy has become standard practice in historical demographic research (Table I). The statistical techniques are relatively simple, the only data needed are long series of vital events and prices, and the results are usually informative. However, previous attempts to measure the impact of price (and sometimes temperature) effects on vital events have always been affected, perhaps flawed, by the somewhat arbitrary choice of start-points and end-points and the assumption that the responses within a given interval are more-or-less the same throughout the interval. Researchers interested in examining whether responses change over time for a given place have usually segmented the time interval for which data were available. The start-points and end-points of these segments were often arbitrarily defined, or based on some fuzzy notion of structural change. This study attempts to address these problems using two methods each with its own particular set of problems and advantages, but both of which should yield similar conclusions.

Background

Figure 1 presents a stylized and somewhat simplified characterization of the impact of annual changes in various more-or-less important environmental factors on annual variations in births and deaths in a preindustrial society. As in most of these types of diagrams the arrows could conceivably connect all the boxes in all directions, with the exception of weather effects which are truly exogenous. The signs and directions of the arrows connected to demographic events generally reflect the cumulative effects a few years after the shock.

The basic idea is that annual changes in births and deaths are largely a result of changes in certain aspects of the economy, weather and social conflict. This is not a new idea (see Galloway, 1988, pp. 278–279 for literature on the subject). What's novel in the present study is the attempt to estimate changes in the timing and magnitude of the preventive, positive, and temperature checks to population growth as a society undergoes economic development.

While there is much debate about long-term Malthusian checks, there is substantial evidence for the existence of short-term positive and preventive checks (see Table I and Galloway, 1988, pp. 275–291). In its simplest formulation, the short-term preventive check can be characterized as the impact over a few years of annual changes in food supply on annual fluctuations in fertility. Similarly, the short-term positive check is reflected in the response of mortality over a few years to annual variations in the food supply.

Annual fluctuations in the food supply can be affected not only by changes in the harvest but also by variations in trade, storage capacity, and distribution. As a consequence it is likely that changes in grain prices are a better proxy for changes in the food supply than simply variations in the amount of the harvest. While an increase in grain prices probably was beneficial to large landowners, most of the population suffered. See Galloway (1988, pp. 276–279) for details concerning the use of yearly changes in grain prices as a suitable proxy for annual changes in food supply per capita specifically, and for living standards generally, in the preindustrial economy.

Short-Term Fertility Responses to Changes in the Economy, Non-Infant Mortality, Temperature, Migration, and Social Conflict

Fertility responses to price increases, the short-term preventive check, can be both biological and behavioral. Biological responses resulting from rising malnutrition include increases in spontaneous abortions, anovulation, amenorrhea, age at menarche, fertility-inhibiting disease, death, and decreases in age at menopause. Behavioral responses might include induced abortion, stress amenorrhea, voluntary contraception, and reduced coital frequency due to abstinence, decreased libido, or spousal separation. Measuring these intermediate variables directly using historical data is problematic. Holding non-infant mortality constant, the effects of price changes on fertility would generally include most of the behavioral responses. Non-infant mortality (total deaths minus infant deaths), which itself may increase as a result of prices, may be a proxy for some of the biological factors. See Galloway (1988, pp. 283–284) for detailed references.

The short-term preventive check appears to be universal in preindustrial regions and countries (Table I). The cumulative elasticity over three to five years of the responses of births to grain prices was about −0.1 to −0.3 in all countries or regions examined with most of the significant responses occurring at lags 0 and 1.

TABLE I: Summary of previous research on annual variations in vital events, prices, and temperature using 'distributed lag' type models

Place	Source	Lag length		Periods	
		Price	Temp.		
England	Lee (1981)	5	2	1548–1640	1641–1745
				1746–1834	1548–1834
England	Weir (1984)	4		1670–1739	1747–1789
				1790–1829	1830–1865
England	Schultz (1986)	5		1668–1760	
England	Bengtsson (1986a)	5		1760–1799	1800–1860
England	Galloway (1988)	5	3*	1546–1674	1675–1755
				1756–1870	
London city	Galloway (1985)	5	3	1675–1825	1706–1825
				1733–1825	
France	Richards (1984)	5	3	1740–1909	
France	Weir (1984)	4		1670–1739	1747–1789
				1790–1829	1830–1865
France	Bengtsson (1986a)	5		1760–1799	1800–1860
France	Galloway (1988)	5	3*	1677–1734	1756–1870
Rouen city	Galloway (1986b)	5		1681–1744	1681–1787
Prussia	Galloway (1988)	5	3*	1696–1755	1756–1870
Hagen county	Hohrst (1977)	6		1817–1890	
Sweden	Bengtsson/Ohlsson (1985)	5		1756–1799	1800–1859
Sweden	Eckstein *et al.* (1985)	5	5	1756–1869	
Sweden	Fridlizius/Ohlsson (1984)	2		1751–1770	1774–1802
Sweden	Schultz (1986)	5		1756–1869	
Sweden	Bengtsson (1986a)	5		1760–1799	1800–1860
Sweden	Larsen (1987)	3		1751–1850	1851–1913
Sweden	Galloway (1988)	5	3*	1756–1870	
Denmark	Galloway (1988)	5	3*	1756–1870	
Arhus diocese	Galloway (1993)	5		1726–1796	
Netherlands	Galloway (1988)	5	3*	1811–1870	
Belgium	Galloway (1988)	5	3*	1811–1870	
Belgium rural area	Mendels (1972)	4		1693–1795	
Tuscany	Galloway (1988)	5	3*	1817–1870	
Austria	Galloway (1988)	5	3*	1827–1870	
Military border	Hammel (1985)	2		1830–1847	
Croatia parishes	Capo (1988)	3		1755–1855	
Spain rural areas	Perez Moreda (1988)	5		ca. 1691–1836	
Spain four cities	Reher (1988)	5		ca. 1661–1795	
New Castile	Reher (1988)	5		1583–1830	
Mexico 3 parishes	Reher (1991)	5		ca. 1754–1809	
Japan	Galloway/Lee (1985)	5		1882–1940	
Japan	Feeney/Kiyoshi (1990)	5		1806–1857	
Taiwan	Galloway/Lee (1985)	5		1914–1938	
Bombay Presidency	Galloway/Lee (1985)	5		1883–1925	

* Galloway (1987).

Notes: Temp. = temperature, Mort. = non-infant mortality, Win. = winter temperature, Spr. = spring temperature, Sum. = summer temperature, Aut. = autumn temperature. Blank spaces indicate that the variable is not used.

The + and – signs indicate the direction of the lag effect if significant within 10%. An ○ indicates not significant within 10%.

Fertility						Nuptiality		Mortality				
Price	Mort.	Win.	Spr.	Sum.	Aut.	Price	Mort.	Price	Win.	Spr.	Sum.	Aut.
−−+−o	−−+−o	o+		+−		−−ooo	−++oo	o++o−	−o		++	
o+o	−−oo					−ooo	−+oo	oo+o				
o−−+o	−+o+							oo+oo				
−oooo	−−ooo					−oooo	o++oo	ooo−o				
−−+oo	−−+oo	o−o	ooo	ooo	ooo	−−+oo	−++oo	o++oo	−oo	ooo	+oo	ooo
								+−ooo	−oo	ooo	+oo	ooo
−+−o	−oooo	ooo		ooo		−+−oo	ooooo	o−+−o	ooo		ooo	
− oo	−ooo					·ooo	o+oo	+ooo				
−−ooo	ooooo					−+ooo	ooooo	oo+−o				
−−+oo	oo+oo	o−o	ooo	ooo	ooo	−+ooo	++ooo	+++oo	ooo	ooo	+oo	ooo
o−ooo	−−−−o					−o+o−	ooooo	++ooo				
o−+oo	− ooo	ooo	ooo	ooo	o++	−oooo	o+ooo	o+ooo	ooo	ooo	ooo	ooo
o ooo						−oooo		ooooo				
								++ooo				
−ooo	oooo	ooooo	ooooo	ooooo	ooooo			+ooo	−oooo	ooooo	ooooo	ooooo
								+o				
o−o+o	−ooo							oo+oo				
− ooo	−oooo					−−ooo	o+++o	++ooo				
						−+−	++o					
o−ooo	−oooo	++o	o+o	o−−	ooo	−−ooo	oo++o	+oooo	−−−	ooo	+oo	+oo
o−ooo	−oooo	o+o	ooo	ooo	ooo	ooooo	o+oo+	ooooo	−−o	ooo	ooo	ooo
o−ooo	−+ooo							ooooo				
−−oo−	−−+oo	ooo	ooo	o−o	ooo	−−ooo	ooooo	oo+oo	ooo	ooo	+oo	ooo
−−+oo	−o+oo	−−o	oo−	oo+	o+o	−−ooo	++o−	oo+oo	o−o	ooo	ooo	ooo
						o−oo						
o−ooo	−oooo	oo+	ooo	ooo	oo−	−oooo	ooooo	oo+−o	oo−	−oo	ooo	ooo
o−+oo	ooo	oo−	ooo	ooo	o++	ooooo	+o+o	+oooo	ooo	oo−	ooo	ooo
−						−o		o+				
−oo	−−o					ooo	−+o	ooo				
o−ooo	−−ooo					− ooo	−++oo	++ooo				
o−ooo	−−ooo					ooooo	o+ooo	+oooo				
o−ooo	−−ooo					−−oo+	oo+oo	++o−−				
o−+−o	ooooo					−oooo	ooooo	+oooo				
oo+oo	ooo+o							+o+−+				
o ooo												
ooooo	ooooo							oooo−				
o−+−o	−−o−o							+−ooo				

The lags are presented in order from left to right; lag 0 is first, then lag 1, then lag 2, and so on.
Where wage or production data are used in place of prices, I have reversed the sign.
Where more than one time period or place is used, I have attempted to indicate the typical pattern.
Schultz (1986), using average annual temperature data, found a significant positive effect at lag 1 on fertility for Sweden, a significant negative effect on mortality at lag 1 for Sweden, and no annual temperature effects for England.

While there is an extensive literature concerning seasonality of births (for recent reviews see Miura, 1987; and Lam and Miron, 1991), there has been very little research examining the impact of changes in seasonal temperature from one year to the next on fertility. Research along these lines is not promising since fertility is affected by both behavioral and biological reactions to weather changes, most of which are difficult to measure.

MacFarlane focuses on the biological response (1977, pp. 573–577). He suggests that the neuroendocrine activity which governs fecundity in the female is reduced when temperatures are above or below some optimal level. Female fecundity should decrease during periods of increasing climatic variability. Sundararaj *et al.* (1978, pp. 29–30) find that shorter menstrual cycles occur in warmer days and longer cycles in colder days and suggest "perhaps increased physical activity or external temperatures in the summer months may trigger endocrine changes".

Another study shows that eclampsia (convulsions associated with pregnancy) rates "are twice as high on cool or humid days than on days with average temperatures or humidities" (Neutra, 1974, p. 833). Slatis and De Cloux (1967, p. 292) suggest that maternal illnesses in winter months cause malformations leading to an observed peak in stillbirths in the spring and note that in the United States the peak period of death due to congenital malformations of liveborn infants is in January. Maternal mortality resulting from complications of pregnancy, childbirth and the puerperium, shows a slight peak in July (Ellis, 1972, pp. 25–26). Age at menarche was found to be higher in cooler areas (Saar *et al.*, 1988, p. 33). A tentative implication of these findings is that temperature extremes, cooler winters and warmer summers, generally reduce fertility although the proposed causal linkages are various and not clearly understood. Historical short-term analyses tend to support this notion. Cooler winters and warmer summers net of price effects generally reduce fertility (Table I). See Galloway (1987, pp. 112–134) for age-specific fertility responses to changes in prices and seasonal temperature in preindustrial Sweden.

Internal migration resulting in temporary or permanent relocations would be valuable for explaining changes in fertility as a consequence of spousal separation. However, annual migration data are not easily found (see Bengtsson (1986b) for one of the few studies on 19th century annual internal migration). Fertility declines resulting from war or civil disturbances generally operate through prices, internal migration, and non-infant mortality and can result in decreased food supply, increased spousal separation and elevated mortality and morbidity.

Short-Term Nuptiality Responses to Changes in the Economy, Non-Infant Mortality, Migration and Social Conflict

Annual fluctuations in nuptiality are unlikely to have a major impact on annual variations in fertility. In other words, annual changes in births as a result of marriages can only be a minor component of annual changes in all births. Lee discusses this notion theoretically (1975, pp. 295–304) and provides empirical support using

English data (1981, pp. 366–368). Galloway (1987, pp. 112–134) provides indirect support when he found that age-specific marital fertility responses to price and non-infant mortality fluctuations in preindustrial Sweden were about the same in all age groups.

Nonetheless, because of its importance to historical demography an analysis of changes over time in the response of nuptiality to prices and non-infant mortality has been included in this study. Substituting nuptiality for fertility in Figure 1 and eliminating the temperature effects provides a useful framework for evaluating short-term fluctuations in nuptiality. Elevated prices probably lead to a reduction or postponement in marriages because of the increased difficulty in setting up a household. A rise in non-infant mortality would increase the number of remarriages and open economic opportunities for others, thereby increasing marriages. On the other hand, mourning might delay some marriages. Although difficult to argue, increased internal migration might have a net negative impact on nuptiality as prospective couples are forced into temporary or permanent separation. War and civil disturbances might tend to postone marriages. See Galloway (1988, pp. 288–289) for detailed references.

Short-Term Mortality Responses to Changes in the Economy, Temperature, Migration, and Social Conflict

Price increases can lead to a rise in mortality as a result of starvation, increased susceptibility to infectious disease as a result of malnutrition, and a general increase in the frequency of infectious diseases, occasionally leading to epidemics, as the population begins to move about in search of food or employment. Where responses are significant, high prices are usually associated with high mortality at lags 0, 1, and 2 (Table I). See Galloway (1985 and 1987, pp. 135–192) for an analysis of cause-specific and age-specific mortality responses to price increases in London and Sweden. A detailed literature review can be found in Galloway (1988, p. 290) and a recent general overview is provided by Walter and Schofield (1989, pp. 1–73).

There is a large literature concerning seasonality of mortality (see for example Sakamoto-Momiyama's (1977) work on many countries, Bradley's (1971) analysis of England, and Buchan and Mitchell's (1875) study of London). Buchan and Mitchell's detailed analysis of seasonality of deaths by cause in London 1845 to 1874 is exemplary. They find that the incidence of respiratory diseases peaks in the winter months and deaths from bowel complaints peak in the summer months. Unfortunately, such analyses can tell us little about the impact of unusually cold winters or unusually warm summers on mortality.

Studies about direct changes in temperature on mortality are more relevant. An obvious consequence of unusually cold weather is an increase in hypothermia. "Advanced age, disorders causing hypometabolism, central nervous system disease, malnutrition, a variety of drugs, and exposure commonly cause hypothermia" (Knochel, 1985, p. 2306). Clark and Edholm (1985, p. 162) note "elderly subjects are more liable to accidental hypothermia than younger age groups because with ageing, in many people although not all, there is an increasing impairment of temperature regulation.... Another age group which is also vulnerable to cold is the very young, particularly young babies under six months old". Thermoregulatory impairment as a result of cold among the elderly is also found by Fox *et al.* (1973, p. 200), Collins *et al.* (1977, p. 353), and Mathew *et al.* (1986, p. 137). Wigglesworth (1973, p. 482) notes increases in hypothermia among infants in extreme winter weather. The major cause of death from hypothermia is ventricular fibrillation leading to heart failure (Wong, 1983, p. 230; Clark and Edholm, 1985, p. 119; Knochel, 1985, p. 2306). A useful review of the literature concerning hypothermia can be found in Lloyd (1986, pp. 49–74).

Neill *et al.* (1974, p. 471) find that cutaneous cold increases blood pressure. Mortality due to stroke increases in winter and shows a negative correlation with temperature in all seasons (Barber *et al.*, 1984, p. 662). Keating *et al.* (1984, p. 1405) suggest that "the increases in platelets, red cells, and viscosity associated with normal thermoregulatory adjustments to mild surface cooling provide a probable explanation for rapid increases in coronary and cerebral thrombosis in cold weather". Campbell and Beets (1979, p. 113) find that "deaths from heart attacks are increased by severe winter weather involving extremely cold temperatures". Knox (1981, p. 222) finds that mortality from acute myocardial infarctions, hypertension, cerebral hemorrhage and thrombosis, and bronchitis increases with colder temperatures in winter months and in summer months.

Bull and Morton's (1978, p. 210) longitudinal analysis is particularly important to the present inquiry. They find that in England in the 1960s death rates in most diseases other than cancers increase as external temperature declines. Respiratory diseases appear to be most sensitive followed by strokes, ischaemic heart disease, hypertension, and gastro-intestinal diseases (1978, pp. 213–221). In an earlier study they found that respiratory infections and vascular diseases increase with declining temperature and that the effects are strongest among the elderly (1975, p. 232). They suggest that "there is probably a causal relationship between temperature change and deaths from a wide variety of diseases. A proximal link in the chain is probably a failure of autonomic control of body temperature in the elderly leading to a change in body temperature and some humoral change which in turn leads to death. It is not appropriate to concentrate on hypothermia as the relationship between temperature and death is seen at all temperatures" (1978, p. 210). They note that "this move from an optimal body temperature might affect the functioning of some critical enzyme system or systems" (1978, p. 222). Larsen (1990a; and 1990b) finds that cold winters are associated with elevated mortality in the United States. Lloyd provides an informative review of the effects of cold on the cardiovascular system, the respiratory system, and cerebral function (1986, pp. 75–158).

Unusually hot weather, especially during the summer, can also increase mortality. Unfortunately contemporary medical studies using United States and European data shed little light on mortality increase in past times resulting from hot summers and their impact on food deterioration, sanitation problems, and infectious disease. Until the last half of the 19th century or even the beginning of the 20th century, it seems likely that greater density and attendant sanitation problems facilitated the spread of disease during hot weather. Ellis (1972, p. 7) notes that "since World War II, the growth of refrigerated food storage and antibiotic and chemotherapeutic advances have reduced to negligible proportions the mortality from many lethal infectious diseases which formerly overshadowed the mortality statistics for climatic stress during the summer months".

Nonetheless, contemporary research concerning the direct effects of excessive heat on mortality is still applicable to earlier times. "Classic heatstroke occurs especially in the poor, the elderly, the chronically ill, alcoholics, patients with advance heart disease, and the obese. Hot, humid, weather of three or more days duration usually precedes epidemics of this disorder. Deaths due to myocardial infarctions and congestive heart failure in patients with cardiovascular disease increase sharply during heat waves because of increased demands placed upon the heart by heat stress" (Knochel, 1985, p. 2305). Similar assessments can be found in Clark and Edholm (1985, p. 119), Ellis *et al.* (1975, p. 8), and MacFarlane (1978, p. 332). Ellis notes that mortality from excessive heat is relatively high during the first year of life, low thereafter up to age 20, rises gradually to age 70, and increases sharply after age 70 (1972, p. 5). Thermoregularoty control is less stable in infants (Ellis, 1972, p. 44) and impaired in the elderly (Foster *et al.*, 1976, p. 91). Useful summaries of environmental heat illnesses can be found in Ellis (1972) and Knochel (1974).

Turning to the effects of weather variability on mortality, a characteristic of periods of climatic cooling is an increase in temperature variability (Galloway, 1987, pp. 59–60). Appraisals by Howe (1972) and Tromp (1980) indicate that extremes in climatic variation appear to increase mortality. Howe (1972, pp. 18–19) 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". Tromp (1980, pp. 149–150, 159, 174, and 225–226) in his exhaustive examination of the biometeorological literature finds that one of the key meteorological factors associated with increasing mortality is increasing variability in the weather. It is likely that a direct result of the increased variability in the weather associated with cooling is an increase in mortality.

Summing up, it is evident that unusually cold weather, especially in the winter, is associated with increased mortality, particularly among the very young and the elderly. Hypothermia, respiratory ailments, and cardiovascular diseases increase with colder weather. Prolonged confinement within poorly ventilated housing would promote the spread of infectious diseases, particularly those transmitted through the air. Excessive increases in summer temperature increase mortality, especially among the very young and the elderly. Rapid changes in the weather, usually associated with periods of cooling, appear to increase mortality. Climatic conditions also affect the mobility and strength of pathogenic micro-organisms and those insects and animals which carry them, although the magnitude of these effects has not been determined. However, where sanitation is virtually unknown and water supplies subject to contamination, it is probable that warm summers promote the spread of infectious diseases through increased proliferation of animal, insect, and bacterial vectors. Finally, malnutrition tends to exacerbate the negative effects of temperature extremes.

Temperature changes independent of economic effects have been found to significantly affect mortality in preindustrial Europe. Cold winters and hot summers, where significant, generally tend to increase mortality (Table I). Post (1985) provides a narrative description of possible effects of temperature change on cause-specific mortality in preindustrial Europe and Galloway (1985; and 1987, pp. 135–192) examines the impact of temperature changes on age-specific and cause-specific mortality in Sweden and London before 1870. Galloway (1987, pp. 56–104) has demonstrated the importance of the effects of cold winters and hot summers on overall mortality in nine preindustrial European countries.

War and civil disturbances can affect mortality by decreasing the food supply, increasing internal migration and epidemics, and of course directly as a result of casualties.

Other Short-Term Interactions

Figure 1 presents other linkages which indirectly affect short-term variations in births and deaths. War and civil disturbances can seriously reduce the food supply by disrupting trade and distribution, reducing storage capacity, and damaging the harvest. High grain prices themselves can generate social unrest (Tilly, 1975; Hufton, 1985; Tilly, 1985). Internal migration can increase because of social conflict and poor harvests. Epidemics are often spawned by an increase in the frequency of interaction among members of the populace. The weather not only affects the harvest in some complicated manner (Slicher van Bath, 1977, p. 57; Galloway, 1987, pp. 58–60; and Pfister, 1988), but can also hamper trade and distribution.

In addition to the weather, other variables in Figure 1 can have exogenous components. For example infectious diseases, possibly becoming epidemic, can be introduced into a society as a result of migration or trade. War, social disturbances, trade, storage capacity, and distribution can be affected by political and commercial decisions. Many areas in Europe were battlefields for foreign opponents. Internal migration can increase because of resettlement policy, urban demand for labor, and external migration. Finally, while we have tried to account for most of the important interactions, it is possible that other factors, perhaps crucial ones, have not been considered.

Secular Changes in the Short-Term Preventive and Positive Checks

Long-term improvements in living standards as a result of economic development should be reflected in changes in the magnitude of the short-term preventive and positive checks. As a result of technological innovation, harvest yields increase, crops become more resistant to disease and weather, trade increases, storage capacity improves, and distribution becomes more efficient. Food availability eventually increases to a point where annual variations in a country's food output per capita should have little impact on annual changes in mortality. Economic development is also associated with improvements in hygiene, sanitation, water supply, housing, clothing, and medical technology which can indirectly reduce both the short-run positive check and the biological component of the short-run preventive check. As mentioned earlier, changes over time in the behavioral component of the short-term preventive check are difficult to assess.

There is little doubt that profound economic changes occurred in many European countries prior to World War I. Attempts to measure long-term changes in living standards in countries, especially before 1850, are fraught with difficulty. One standard measure is urbanization which is reflected below using data compiled by de Vries (1984, pp. 39, 45–46, 309–321). The data for Sweden are drawn primarily from Statistika Centralbyrån (1969, pp. 61–65, 86–97) and Stockholms Stads Statistika Kontor (1907, pp. 67–68). Percent urban shown below is based on the number of persons living in towns with populations exceeding 10,000 divided by the total population of the country.

	England and Wales	France	Germany	Sweden
1500	3.1	4.2	3.2	
1550	3.5	4.3	3.8	
1600	5.8	5.9	4.1	
1650	8.8	7.2	4.4	
1700	13.3	9.2	4.8	
1750	16.7	9.1	5.6	3.4
1800	20.3	8.8	5.5	4.2
1850	40.8	14.5	10.8	4.7
1890	61.9	25.9	28.2	13.8

Maddison (1982, p. 8) provides some very rough estimates of gross domestic product per capita in 1970 U.S. prices.

	United Kingdom	France	Germany	Sweden
1700	288	275		
1820	454	377	310	307
1870	972	627	535	415

When using countries as units of analysis, the poorer segments of the population are most likely to suffer the effects of the short-term preventive and positive checks (Galloway, 1988, pp. 277–278). As a consequence we would be interested in looking at changes over time of some measure of welfare of the poor, especially some measure of rural living standards. Crop yields began to increase in most of Europe after 1750, with the England-Ireland-Belgium-Netherlands group experiencing yields twice those of the rest of Europe by 1820 (Slicher van Bath, 1967, p. 95). Yields in the group of France, Italy and Spain actually appear to decline from 1750–1799 to 1800–1820.

	England, Ireland, Belgium, Netherlands	France, Italy, Spain	Germany, Switzerland, Denmark, Sweden, Norway
1150–1199		3.2	
1200–1249	3.7		
1250–1299	4.7		
1300–1349	4.1	4.8	
1350–1399	5.2		
1400–1449	4.6	4.9	
1450–1499	5.1		
1500–1549	7.3	6.7	4.0
1550–1599	7.3		4.4
1600–1649	6.5		4.5
1650–1699	7.0	6.4	4.1
1700–1749		5.8	3.8
1750–1799	10.1	6.9	4.8
1800–1820	11.1	5.6	5.5

Bairoch has calculated an index of the level of agricultural development in 19th century European countries. In the following table 100 equals the net annual production of 10 million vegetable-based calories per male worker in agriculture (Bairoch, 1973, p. 472).

	United Kingdom	France	Germany	Sweden
1810	140	70		65
1840	175	115	75	75
1860	200	145	105	105
1880	235	140	145	115
1900	225	155	220	130

While each country experiences increases over time, we see that by 1900 agricultural output per capita in England and Germany was about 50 percent greater than either France or Sweden. Indeed, French agricultural production was about the same as Sweden's. Low productivity in France compared to England typically has been attributed to France's relatively large proportion of small farms (Terbilcock, 1981, p. 133) or differences in regional ecology and land use (Goldstone, 1988, p. 288).

The above measures generally suggest some parity, or at least no striking differences, in economic development in 17th century France and England. However, by the 19th century we see England economically outdistancing all countries, with France falling behind both Germany and England in the last half of the 19th century.

Of particular interest is the relative low agricultural output per capita in France and Sweden compared to England and Germany. Based on these data we would expect that peasants and farmers with small landholdings in France and Sweden would be less insulated from shocks in the food supply than those in Germany or England, particularly in the latter half of the 19th century. In other words, we expect the positive check to be relatively stronger in these countries. It is more difficult to say anything about the relative strengths of the preventive check since it comprehends both behavioral and biological factors. Concerning trends over time, we would expect a decline in the positive check in all countries with more pronounced decreases in England and Germany.

Earlier research suggests that the short-term positive check appeared to be strongly negatively correlated with measures of welfare in preindustrial European countries (Galloway, 1988, 291–298). The short-term preventive check was significant and about the same magnitude in all countries. These findings were generally based on the responses of mortality and fertility to price changes in countries during the period 1756–1870. The results were compared to overall estimates of the average level of urbanization and per capita income during this period. These cross-sectional results support the notion that as living standards increase the short-term positive check fades and suggest that within a given country the short-term positive check should diminish as living standards rise.

Secular Changes in the Short-Term Temperature Checks

We might expect a reduction in the magnitude of the temperature checks to population growth over time as a result of increased living standards. Improvements in housing, ventilation, heating, clothing, food storage, and nutrition (leading to increased immuno-competence) can reduce the impact of cold winters on mortality. Improved sanitation, water supply, and food storage can diminish the effects of hot summers.

Temperature levels themselves probably changed gradually over the long-term with cooler temperatures found during the Little Ice Age of the 17th century (see Galloway, 1986a for estimates of long-term fluctuations in global temperature and their possibhle impact on population growth). From around 1660, when instrument data first become available, to around the beginning of the 20th century, there is a slight but fairly consistent warming of winter temperature and a slight cooling of summer temperature in England, France, Prussia, and Sweden (see Appendix Tables I to IV).

Other Long-Term Considerations

The primary long-term factor affecting changes in the short-term preventive, positive and temperature checks to population growth is probably economic development. The slight moderation of winter and summer temperatures also may have an independent impact on secular changes in the temperature checks. Other possible, but unmeasurable, candidates might be the introduction, extinction, or change in the virulence of micro-organisms and diseases themselves, as well as the vectors that spread them. Changes in tastes or norms independent of economic development can also affect the behavioral components of the preventive check. There seems to be little evidence to suggest that the frequency and intensity of the impact of war and civil disturbances on mortality and fertility either increased or decreased in Europe prior to World War I. Of course, other long-term factors not known to the author might also be important.

Data and Periods

We will examine changes over time in the short-term preventive, positive and temperature checks to population growth in England, France, Prussia, and Sweden. These countries are used because they have the longest and oldest series of vital events currently available. Furthermore, England was the most industrialized country in Europe by the end of the period under consideration, Sweden one of the least, with Prussia and France somewhere in between. England and France have a characteristically maritime climate, while Prussia and Sweden's climates are more continental.

As shown in Figure 1, sufficient data are available to convincingly test the preventive and temperature-fertility checks. Price, non-infant mortality, and seasonal temperature data are available, while only internal migration data are lacking. Testing the positive and temperature-mortality checks is more problematic. While we have information on prices and seasonal temperatures, epidemics, internal migration, wars, and civil disturbances are not included in the model. Data concerning war, civil disturbances and major epidemics are not easily incorporated into the model because it is difficult to measure the relative magnitude of their impact and because they are often associated with high prices.

Because short-run fluctuations in mortality in Europe before 1660 are dominated by plague outbreaks, and because temperature data are not available until 1659, the investigation of the more fully specified models is confined to the period 1670 to 1909. These dates and all dates mentioned henceforth are for the detrended series, the detrending method being described below. This era can be characterized as post-plague and pre-World War I. There was a major plague outbreak in the Baltic states in 1709, but this was either before the periods or outside the areas examined in this study.

The period used for England and France is 1670–1909. The periods for Prussia, 1700–1909, and Sweden, 1740–1909, begin later due to lack of data. Furthermore, because of data unavailability nuptiality regressions for France and Sweden do not begin until the middle of the 18th century. See Appendix Tables I to IV for summary statistics for each country. The data sources can be found in the Data Appendix. We will also look at the preventive check in Florence beginning in 1460 and Augsburg beginning in 1510 simply because these are two of the oldest continuous long series of births available.

It should be noted that the French series of births and deaths before 1740 are based on indices provided by Didier Blanchet of the Institut National d'Études Démographiques to whom I am very grateful. The indices are highly correlated with actual births and deaths during the period in which they overlap, 1740–1789. There appears to be substantial underregistration of deaths before 1670, although mortality registration seems to be fairly complete by 1740.

Temperature changes should affect mortality (and fertility) differently depending on the season. As a consequence four temperature variables have been constructed: winter is the average of January, February and March; spring the average of April, May, and June; summer the average of July, August, September; and autumn the average of October, November, and December. The oldest long series of instrument-measured monthly temperature data cover Central England beginning in 1659. The oldest continuous series of French temperature data begin in 1757 for Paris, in 1700 for Berlin, and in 1739 for Stockholm-Uppsala. Sources can be found in the Data Appendix.

Annual changes in seasonal temperature in western and central Europe are highly correlated as shown below. The bivariate correlations use detrended data (the detrending procedure is described below) for Central England 1664–1909, Paris 1762–1909, Berlin 1705–1909, and Stockholm 1744–1909. Because of their high correlations, the French seasonal temperature series could be estimated back to 1664 based on Central England data.

Winter in bold, spring in italics:

	England	Paris	Berlin	Stockholm
England	1.0	*0.82*	*0.49*	*0.45*
Paris	**0.85**	1.0	*0.65*	*0.45*
Berlin	**0.82**	**0.78**	1.0	*0.69*
Stockholm	**0.68**	**0.51**	**0.75**	1.0

Summer in bold, autumn in italics:

	England	Paris	Berlin	Stockholm
England	1.0	*0.73*	*0.58*	*0.39*
Paris	**0.82**	1.0	*0.77*	*0.37*
Berlin	**0.57**	**0.64**	1.0	*0.56*
Stockholm	**0.46**	**0.41**	**0.74**	1.0

Methodology

When examining at short-run effects, it is necessary to remove long-term trends from all series. Each variable is detrended by dividing each data point, call it x, in a series by an eleven year average of data points centered around x (Lee, 1977; and Lee, 1981, p. 358). All series are detrended in this manner. This method of detrending, when used in regression analysis, yields regression coefficients that are elasticities.

A realistic analysis of the responses of demographic events to changes in prices or temperature should allow these responses to vary over some period of time subsequent to an initial price or temperature shock. The distributed lag model is a useful and simple technique for this type of analysis (Pindyck and Rubinfeld, 1981, p. 231). However, the distributed lag model demands some prior notion of lag length. Previous work along these lines suggests that distributed lags of 0, 1, 2, 3, and 4 are appropriate for demographic and price interactions (Table I). Appendix Table V presents estimates of annual lag lengths for various variables using the Akaike AIC criterion (Judge *et al.*, 1988, p. 728). It should be understood that this criterion is purely statistical and devoid of any theory whatsoever. Realizing that plague events probably distort the outcomes significantly, the series have been divided into plague and post-plague eras. The median and mean lag lengths for England, France, Prussia and Sweden using post-plague data from Appendix Table V are summarized below (0 means lag 0; 1 means lags 0 and 1; 2 means lags 0, 1, and 2; and so on).

	Median	Mean
Vital rates = f (price)	2	3.2
Vital rates = f (non-infant mortality)	2	3.4
Fertility = f (seasonal temperature)	1	2.4
Non-infant mortality = f (seasonal temperature)	0.75	1.9
Mortality = f (seasonal temperature)	0.75	1.9

The mean is almost always larger than the median because, on observation, the Akaike AIC criterion seems to be very sensitive to outliers. Based on the above summary table, lag lengths of 0, 1, 2, 3, and 4 appear to be appropriate for the price and non-infant mortality independent variables in the post-plague era. Mortality responses to prices in Prussia may go to lag 6, but that appears to be an exception. Lags 0, 1, and 2 seem about right for the seasonal temperature independent variables, although fertility responses to seasonal temperatures might go to lag 3. A distributed lag model will be used in this analysis with price and non-infant mortality variables lagged 0, 1, 2, 3, and 4 years and seasonal temperature variables lagged 0, 1, and 2 years.

For purposes of this study the short-term preventive check is the sum of the responses over five years of fertility to price changes controlling for non-infant mortality and temperature effects. Similarly, the short-term positive check is the cumulative response over five years of mortality to price changes independent of temperature effects. The short-term temperature-fertility check is the cumulative response of fertility over three years to seasonal temperature changes independent of price and non-infant mortality effects. The short-term temperature-mortality check is the cumulative response of mortality over three years to seasonal temperature changes net of price effects. The methods described below allow for the examination of the various checks at each lag, which is necessary when looking at changes in timing. However, the lag sum is particularly useful because it measures the overall net effect.

Method 1, the Fifty Year Interval Model

The first method simply runs regressions using fifty year intervals every ten years. Experiments suggest that correcting for serial correlation becomes problematic when using shorter periods, especially those less than thirty or forty years (see also Harvey, 1981, pp. 189–198). Furthermore, some of the larger models involve as many as 22 independent variables which may generate degrees of freedom problems in shorter series.

The resulting elasticities are plotted and examined to see if there are any changes in the responses over time. This method is not without problems. It forces one to look at the world in terms of fifty-year segments. One can observe trends but cannot measure their significance. It is not of much use if data are available for only short periods, say 50 to 80 years. Any particular fifty year regression might be strongly affected by outliers. On the positive side, the method is easy to understand. When looking at long-term trends it does not force the data to conform to any particular mathematical function. This is especially important when hypothesizing structural change. It is fairly illuminating when displayed graphically.

Method 1 Equations

The number of observations is always 50 and the regressions are run every ten years to cover the entire time period from when data are first available to 1909. The time periods and summary measures of the data can be found in Appendix Tables I to IV. For example, the impact of prices on births is estimated as follows where, B is detrended births, P is detrended prices, a is a constant, b is a regression coefficient, T is calendar year time and e is an error term:

$$B_T = \mathrm{a} + \sum_{k=0}^{4} \mathrm{b}_k P_{T-k} + e_T. \quad (1)$$

This is Equation A in Table II. Equations A to I in Table II are generalizations of the one shown above. All the important findings are presented graphically in Figures 2 and 3b to 9b.

Correction for second order autoregressive disturbances is accomplished using the Cochrane-Orcutt iterative procedure where the error process is defined as $e_T = v_1 e_{T-1} + v_2 e_{T-2} + u_T$ where T is time, e is the error term, u is an independently distributed random variable, and v is a coefficient (Pindyck and Rubinfeld, 1981, pp. 152–157). 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 it should provide a better estimate of their significance (Harvey, 1981, pp. 189–198). Note that in the figures the temperature regression coefficients are in terms of a one degree Fahrenheit increase (these can be converted to Centigrade by multiplying by 1.8).

Method 2, The Interactive Model

Method 2 makes use of the so-called interactive model (Pindyck and Rubinfeld, 1981, p. 110). This formulation allows the responses of the dependent variable to change as a function of time by incorporating linear and quadratic interaction terms into the equations. Time used as an independent variable in this sense may be thought generally to reflect economic development, technological change, or capital accumulation, as well as other factors discussed earlier.

There are problems with this method. The long-term trend is forced to conform

TABLE II: Equations used in the analysis

Method 1, the fifty year interval model:		
A.	Fertility	= f(prices).
B.	Fertility	= f(prices, non-infant mortality).
C.	Fertility	= f(prices, winter, spring, summer, autumn).
D.	Fertility	= f(prices, non-infant mortality, winter, spring, summer, autumn).
E.	Nuptiality	= f(prices, non-infant mortality).
F.	Mortality	= f(prices).
G.	Mortality	= f(prices, winter, spring, summer, autumn).
H.	Non-infant mortality	= f(prices).
I.	Non-infant mortality	= f(prices, winter, spring, summer, autumn).
Method 2, the interactive model:		
AA.	Fertility	= f(time, prices, prices*time).
BB.	Fertility	= f(time, prices, prices*time, non-infant mortality, non-infant mortality*time).
CC.	Fertility	= f(time, prices, prices*time, winter, winter*time, spring, spring*time, summer, summer*time, autumn, autumn*time).
DD.	Fertility	= f(time, prices, prices*time, non-infant mortality, non-infant mortality*time, winter, winter*time, spring, spring*time, summer, summer*time, autumn, autumn*time).
EE.	Nuptiality	= f(time, prices, prices*time, non-infant mortality, non-infant mortality*time).
FF.	Mortality	= f(time, prices, prices*time).
GG.	Mortality	= f(time, prices, prices*time, winter, winter*time, spring, spring*time, summer, summer*time, autumn, autumn*time).
HH.	Non-infant mortality	= f(time, prices, prices*time).
II.	Non-infant mortality	= f(time, prices, prices*time, winter, winter*time, spring, spring*time, summer, summer*time, autumn, autumn*time).

Notes: All variables except time are detrended as discussed in the text.
Fertility is CBR when available, births otherwise. Nuptiality is CMR when available, marriages otherwise. Mortality is CDR when available, deaths otherwise. Non-infant mortality is non-infant deaths*1000/population when available, non-infant deaths otherwise. Prices are wheat prices in England and France, rye prices in Prussia and Sweden. Winter is average winter temperature, (January+February+March)/3. Spring is average spring temperature, (April+May+June)/3. Summer is average summer temperature, (July+August+September)/3. Autumn is average autumn temperature, (October+November+December)/3. Time is calendar year time.
The price, non-infant mortality, price interaction, and non-infant mortality interaction independent variables are each distributively lagged five years.
The temperature and temperature interaction independent variables are each distributively lagged three years.
See Appendix Tables I to IV for periods used and summary measures of raw and detrended data for England, France, Prussia and Sweden. The period used in the regressions begins in 1670 and ends in 1909, subject to data availability. This period can be characterized as post-plague and pre-World War I. In Method 1 regressions are run using fifty year intervals every ten years. In Method 2 a regression is run for the entire period. These regression results are summarized in Figures 3a to 9b.
A special set of regressions is run using Method 1 and Equation A for the very old series of births found in Florence (1460–1909), Augsburg (1510–1799), France (1510–1909), and England (1550–1909). These regression results are summarized in Figure 2.

to some designated mathematical function. This may be somewhat less of a problem if one is guided by some strong theoretical justification for some particular function. Of course one can simply use Method 1 first to get some idea of the functional form of the trend. The interactive model can increase degrees of freedom substantially depending on the trend's functional form which can be a problem when dealing with short series. Using this method has some advantages, assuming one has a good approximation of the trend's functional form. It provides estimates of the statistical significance of the trend, for short series (50 to 80 years) one can say something about the trend of the responses, and only one regression need be run.

Method 2 Equations

Looking at the response of births to prices using a linear interactive model and the same terminology as above and where b, c, and d are regression coefficients and T is time we have:

$$B_T = \mathrm{a} + \sum_{k=0}^{4} \mathrm{b}_k P_{T-k} + \mathrm{c}T + \sum_{k=0}^{4} \mathrm{d}_k T P_{T-k} + e_T. \tag{2}$$

In order to estimate the change over time of the impact of prices on births we differentiate the above equation with respect to prices and obtain:

$$\partial B_T / \partial P_{T-k} = \mathrm{b}_k + \mathrm{d}_k T. \tag{3}$$

In this case, b_k is the zero intercept and d_k is the slope. The equations used in the interactive model regression analysis are designated AA to II in Table II. They are all generalizations of the above. The important regression results are displayed graphically in Figures 3a to 9a.

According to the above specification, the long-term trend in the responses is constrained to be linear while an examination of the results of Method 1 may occasionally indicate otherwise. Depending on one's theoretical expectations, further tests for non-linearities and the use of spline functions may be warranted (for a discussion of some of these tests see, for example, Pindyck and Rubinfeld, 1981, pp. 107–137). A cursory inspection of some of the graphs of the results of Method 1 suggested that the change in responses over time might be modelled generally by a third order polynomial. However, experiments with this specification often resulted in unrealistically large movements of the trend line, especially near the end-points. This specification also forced a considerable increase in degrees of freedom. For purposes of this study a linear trend will be used throughout as a rough but parsimonious approximation of the long-term trend. This will allow us to gain some insight into the statistical significance of the long-term linear trend, always keeping in mind the information obtained from Method 1.

Secular Changes in the Short-Term Preventive Check

It was suggested earlier that the preventive check appears to be universal. While there has been a substantial amount of research on various countries, the periods have been restricted to post-1670 with the exception of England (Table I). Figure 2, which graphs the results of Method 1 using Equation A, reveals the existence of the preventive check in areas for which we have earlier data. The Florence series begins in 1460, Augsburg 1510, France 1510, and England 1550. Equation A is the simplest specification of the preventive check, but it will be shown later that adding other variables has little effect on the basic patterns. The first row of boxes shows the response of fertility to a price increase at lag 0 in each of the four areas, the second row shows lag 1, the third row lag 2, and the fourth row the lag sum. Each tiny column within a box is the elasticity in a fifty year interval with its level of significance. The scales are identical throughout in order to facilitate comparisons.

Note that the greatest effect is generally found one year after the price increase, not surprising considering gestation takes nine months, and that the elasticities for both lag one and the lag sum range from around −0.1 to −0.3. When looking at the lag sum, there appears to be little long-term change in the magnitude of the preventive check over time in Florence and Augsburg. In France it diminishes in a rather dramatic monotonic fashion after 1580. In England it appears to weaken around the beginning of the 19th century.

Figure 3a presents the results of various specifications of the short-term preventive check using Method 2. Recall that the period has been restricted to post-plague and pre-World War I, i.e., beginning in 1670 subject to data availability and ending in 1909, and that the long-term trend has been constrained to be linear. Looking at the first box in Row A, we see the changes over time by lag in the preventive check in England. The numbers to the right of each thin line indicate the lag, the letters the significance of the line's slope. The thick black line is the lag sum.

Three specifications of the preventive check model are used: Row A is simply the response of fertility to an increase in prices, Row B is the response of fertility to an increase in prices independent of non-infant mortality effects, Row C is the response of fertility to an increase in prices independent of non-infant mortality and temperature effects. Figure 3a suggests that the three different specifications yield about the same results, although emphasis always will be given to the more fully specified model which in this case is shown in Row C.

Before interpreting Figure 3a, it would be helpful to take a quick look at Figure 3b. Figure 3b shows the lag sum response of fertility to an increase in prices using Method 1 with places, periods, and scales corresponding to Figure 3a. This provides a useful, if summary, check of the validity of the linear constraint on the interaction term in Method 2. The thick black line in Figure 3a should roughly match the pattern of the tiny columns in Figure 3b.

Returning to the lines of Figure 3a, we see that the linear interaction model provides some useful visual interpretations. The lag sum, the thick black line, is simply the arithmetic sum of the thin lines. Changes in timing of the responses are indicated by crossed thin lines. Where there are no crossings of the thin lines, there are no changes in timing. Where a line crosses the 0-axis, a reversal in the direction of the effect is indicated.

Looking at Row C in Figure 3a we see a significant secular monotonic decline in the lag sum preventive check in France, which probably began around 1580 (see Figure 2). Weir (1984, pp. 38, 42) obtains similar results using the periods 1670–1739, 1790–1829, 1830–1865. Long-term changes in the lag sums in other countries are less obvious and not significant. Recall that the preventive check has both behavioral and biological components, thus rendering causal inferences problematic. Holding adult mortality and temperature effects constant as in Row C, and assuming that there was little change in living standards in France between 1670 and 1800, one might speculate that the decline in the preventive check in France was a result of changes in reproductive behavior.

Secular Changes in the Short-Term Nuptiality Response to Increases in Prices and Non-Infant Mortality

The response of marriages to changes in prices and non-infant mortality in England, France, Prussia, and Sweden is shown in Figures 4a and 4b. As seen in Row A, long-term changes in the nuptiality lag sum response to prices are significant in all countries except Prussia. England appears to have shifted from a regime of fulfillment of delayed marriages to one where marriages are permanently postponed as a result of high prices. Looking at the lag sum in the other three countries, there is an apparent shift from an early regime characterized by permanent reductions in marriages as a result of high prices to a later regime in which marriages are unaffected by price changes. The secular change in the lag sum nuptiality response to prices in France is similar to that of the lag sum fertility response to prices. This finding supports the existence of a long-term diminution of the preventive check in France, i.e., a transition from large negative elasticities earlier to virtually no effect by 1900.

The impact of changes in non-infant mortality on marriages is shown in Row B. Most of the nuptiality response to non-infant mortality increases is due to remarriages (Lee, 1981, p. 362; and Galloway, 1987, pp. 105–111). We can see that the English remarried less often in response to elevated mortality after 1800. The lag sum response in France and Prussia was about the same throughout the period considered, although there were shifts in timing, possibly related to changes in the mourning period. Like England, the Swedish lag sum remarriage response shifted dramatically. The last box of Row C suggests a marked decline in the importance of remarriage in Sweden after 1800.

Secular Changes in the Short-Term Positive Check

The response over time of mortality to changes in prices is shown in Figures 5a and 5b. We would expect a general decline in the magnitude of the positive check as living standards rise. Unlike the preventive check which is about the same in all specifications, controlling for temperature effects appears to be important, especially in 17th century France. Looking at the lag sum responses, say in Figure 5b, the positive check seems to disappear in England after around 1730, with a possible slight recrudescence after 1860. France on the other hand experiences either an increase or no change in the positive check over time, depending on which model is used. In fact France's largest elasticity in all three models is found during the last period 1860–1909. Whatever specfication is used, there is certainly no decline in the magnitude of the positive check over time in France. A similar pattern emerges for Sweden, while interpreting changes in the positive check in Prussia is problematic.

Comparing Secular Changes in the Short-Term Preventive and Positive Checks

The importance of changes over time in the positive check relative to the preventive check is summarized in Figures 6a and 6b. Looking at the lag sum responses, we see a slight long-term diminution in the preventive checks in all countries, the most pronounced found in France. We see a similar long-term decline in the strength of the positive check in England and Prussia which is expected based on the trends in measures of economic development discussed earlier. On the other hand, the positive check appears to increase in France and Sweden. It was shown earlier that agricultural output per capita was significantly lower in France and Sweden in the 19th century, suggesting that the poor would be more vulnerable to fluctuations in grain prices than in England or Prussia. Still it is difficult to explain an apparent long-term increase in the strength of the positive check.

Summing up, we see substantial changes over time in the short-term preventive and positive checks to population growth. The linear constraint imposed on the interaction terms in Method 2 generally conforms to the patterns generated using Method 1. The preventive check diminishes marginally in England, Prussia, and Sweden, and declines dramatically in France. While the positive check decreases to near zero in England and Prussia, it either increases or remains strong in France and Sweden.

Secular Changes in the Short-Term Temperature-Fertility Check

It was suggested earlier that warm winters and cool summers might increase fertility, although the theoretical mechanisms involved are not at all clear. Figures 7a and 7b display the changes in impact over time of the short-term temperature-fertility check by season. Note from the vertical scale that these effects are very small. Generally, warm winters and autumns and cool springs and summers seem to be associated with increased fertility. Sweden experiences the most dramatic long-term changes, probably associated with the impact of general economic development on housing and hygiene. In the 18th century fertility increased significantly with warm winters, warm springs and cool summers.

Secular Changes in the Short-Term Temperature-Mortality Check

The mortality responses to temperature changes can be seen in Figures 8a and 8b.

We hypothesize that cold winters and hot summers increase mortality with spring and autumn effects falling somewhere in between. Recall that cool winters are particularly associated with increased respiratory ailments and an increase in the incidence of highly contagious diseases in general. In Figure 8a we see that the winter check is negative at nearly all lags, as expected, with a significant diminution over time found only in England.

Looking at Figure 8a, it might appear at first glance that warm winters tend to increase mortality in late 19th century England. Examination of Figure 8b suggests that in fact there is no significant impact of winter temperature change on mortality in England after 1800. The lag sum in Figure 8a is simply a result of the linear constraint imposed on the regression in Method 2. Such apparent anomalies are infrequent in this study and can usually be resolved by recourse to the results of Method 1, as in this case.

Elevated mortality from hot summers is generally due to gastro-intestinal diseases associated with poor hygiene, bad sanitation, and food contamination. The summer check as shown in Figure 8a and perhaps more appropriately in Figure 8b is very strong everywhere in the 17th and 18th centuries and tends to weaken dramatically in the 19th century. Because the causal mechanisms involved in the summer temperature check to mortality are fairly straightforward, the analysis suggests that the long-term decline in death rates observed to begin around the end of the 18th century in these countries may have been related to improvements in hygiene, sanitation, water-supply, and food quality and availability.

Comparing Secular Changes in the Short-Term Temperature Checks

Figure 9a compares the secular trends in the short-term temperature fertility and mortality checks. The temperature-mortality check tends to overwhelm the temperature-fertility check in nearly all cases. The winter and summer checks are particularly interesting because they should generally reflect the most profound effects. While the summer-mortality check declines everywhere, England is the only country to experience significant diminution in both the winter and summer mortality checks.

Using Real Wages in Place of Grain Prices 1820—1909

While grain prices are certainly a useful measure of annual changes in living standards in the preindustrial setting, the present study covers the last half of the 19th century, a period in which some of the countries under examination were fairly far along the path toward industrialization. It is useful to wonder whether fluctuations in grain prices are a relevant measure of changes in living standards after a certain level of development has been reached. As the proportion of the household budget allocated to food purchases decreases, variability in food prices might become a less effective measure of changes in living standards.

In order to assess this problem, annual real wages were used in place of annual grain prices in the Method 1 analysis of the period 1820 to 1909. Nominal wages in the agrarian and industrial sectors were weighted based on percent of labor force agrarian and percent industrial to arrive at some overall estimate of the nominal wage. The resulting nominal wage series was divided by a consumer price index to produce a real wage. There are problems with using real wages. These include definitions of the nominal wage, construction of consumer price indices, representation of the series, and coping with large gaps in the series. Furthermore, data needed to construct long, continuous, and representative series of annual nominal wages for countries before the middle of the 19th century are usually nonexistent or unreliable. Despite these limitations, the general results (not shown) of the Method 1 analysis using real wages in place of grain prices from 1820 to 1909 in England, France, Prussia, and Sweden were substantively the same as those obtained using grain prices.

Discussion

It is always difficult to be precise about the importance of variables proxied by a secular trend, and even more difficult to specify the causal linkages involved. While nearly everyone agrees that during the period under consideration there were long-term improvements in food supply, production, trade, distribution, hygiene, sanitation, and perhaps general living standards, it is problematic to assess their relative levels of importance to secular changes in the preventive, positive, and temperature checks.

Nonetheless we do observe a general secular diminution in the positive and temperature checks in England. By around 1900 the English were virtually insulated from these kinds of environmental shocks. Other countries were less fortunate. While the temperature checks had diminished in most countries by around 1900, the positive check in France and Sweden was as strong or even stronger than it had ever been.

Examination of the French and English experiences is instructive. There was little difference in the relative strengths of the preventive and positive checks in England and France from around 1670 to 1730. Most economic measures suggest that neither country was more developed than the other. The demographic picture changed dramatically in the 18th and 19th centuries as the positive check began to decline in England and to increase in France. The preventive check remained fairly constant in England throughout, but appears to have declined dramatically in France. Around the middle of the 18th century, England began to outdistance other countries in terms of economic development.

Accounting for the protracted positive check in France is difficult. One explanation might be found in the substantially lower productivity of the agrarian sector in France compared to England. Lower agricultural output per capita tends to increase exposure of the poor to the vagaries of the annual harvest. However, while the level of output was certainly lower in France than in England in the 19th century, most socioeconomic measures seem to suggest a gradual long-term increase in living standards in France, with perhaps some acceleration after 1800. A constant or increasing positive check coincident with increasing economic development seems anomalous.

One conceivable explanation lies in the use of averages as our proxy measures for economic development. The mean can rise when the upper and middle income groups experience significant increases while the living standards of the poor stagnate or decline. When using countries as units of analysis, the checks probably reflect responses of the poor (Galloway, 1988, p. 277).

An alternative explanation might be found in the differences in the relative strengths of the preventive and positive checks. It is possible that these demographic responses to scarcity might themselves affect economic development. Suppose two countries having about the same standard of living must experience an identical reduction in population growth as a result of short-term scarcity. Assuming no out-migration this can occur by increasing mortality, decreasing fertility or by some combination of the two. Countries whose population reduction is dominated by the preventive check will experience a more efficient use of their resources, as opposed to those where the positive check is more important. In other words, in a dominant positive check regime, resources are wasted, relatively speaking, on infants and children who ultimately die as a result of some short-term decrease in per capita food supply. In a dominant preventive check regime, where fertility is reduced as a result of some short-term decrease in per capita food supply, such resources could be directed toward more useful enterprises.

The empirical findings of this analysis suggest that France experienced a significant long-term decrease in the preventive check combined with a persistantly high positive check. *Ceteris paribus*, countries dominated by the positive check are relatively inefficient resource users. They would tend to experience slower economic development. Retarded economic growth itself may also contribute to a more persistent positive check. This scenario suggests one possible explanation for France's slow progress toward industrialization in the 19th century. For many other explanations see, for example, Crouzet (1967), Landes (1969), Crafts (1976), and Trebilcock (1981).

In England, on the other hand, the positive check virtually disappeared around 1730 while the preventive check persisted and did not decline until around the middle of the 19th century. The early disappearance of the positive check may have tended to free up resources that might have been wasted on early deaths, providing some impetus toward more efficient resource allocation, which in turn may have made some contribution toward England's relatively early industrialization.

Summary

The main findings of this analysis are:

1. Fertility declines as grain prices increase (the short-term preventive check) in all countries and cities examined. This response diminishes significantly over time in France.

2. Nuptiality appears to decline as a result of grain price increases. This effect weakens over time in France and Sweden.
3. Mortality increases as grain prices increase (the short-term positive check). This response persists in France and Sweden, but seems to disappear in England around the middle of the 18th century.
4. There is only a weak association between seasonal temperature fluctuations and variations in fertility.
5. Cold winters and hot summers are associated with high mortality. The impact of hot summers on mortality appears to weaken in the 19th century in all the countries examined.

Appendix I: Data

(All data are for the calendar year and all dates are for the raw series unless stated otherwise.)

Florence 1455–1914

Births 1455–1849 are from Zuccagni-Orlandini (1848, pp. 420–507). Births 1840–1914 are from Bandettini (1961, p. 101). The two series are spliced after detrending.

Wheat prices 1450–1914 are based on the following: Florence wheat prices 1450–1566 from Goldthwaite (1975, pp. 33–34); Siena wheat prices 1557–1757 from Parenti (1942, pp. 27–28); Florence wheat 1748–1890 from Mauri *et al.* (1970, p. 645) and Bandettini (1957, p. 13); Italy wheat from 1881–1914 from Istituto Centrale di Statistica (1958, p. 173). The series are spliced after detrending.

Augsburg 1505–1804

Births 1505–1804 are from Schreiber (1940, pp. 103–123, 164–167).

Rye prices 1500–1804 are Augsburg rye prices from Elsas (1936, vol. 1, pp. 685–688).

England 1545–1914

CBR, CMR, and CDR 1545–1871 are from Wrigley and Schofield (1981, pp. 503–535). CBR, CMR, and CDR 1872–1914 are from Mitchell (1981, pp. 123, 130).

Infant mortality rate 1539–1838 is estimated from life expectancy and life table data from Wrigley and Schofield (1981, pp. 230, 714). Infant mortality rate 1839–1914 is from Mitchell (1981, pp. 137, 139, 141).

Wheat prices 1540–1914 are based on the following: England wheat prices 1540–1604 (harvest year) from Bowden (1967, pp. 817–821); Windsor wheat prices 1595–1667 from Smith (1776, book 1, chapter 11); Winchester wheat prices 1658–1817 from Beveridge (1939, vol. 1, pp. 81–84); England wheat prices 1808–

1914 from Mitchell and Deane (1962, pp. 488–489). The series are spliced after detrending.

Monthly temperature data 1660–1914 are for Central England from Manley (1974, pp. 393–397).

France 1505–1914

Birth indices 1500–1789 and death indices 1560–1789 were obtained from Didier Blanchet of Institut National d'Études Démographiques. Births and deaths 1740–1789 are available from 'Institut National d'Études Démographiques (1977, pp. 332–333). The indices are highly correlated with vital events where they overlap (1740–1789). I estimated births 1500–1739 based on the ratio of births to birth index during the period 1740–1749. Deaths 1560–1739 were estimated in a similar manner.

Births 1500–1745 and deaths 1560–1745 are from above. From 1740–1914 vital rates are used. CBR, CMR, CDR 1740–1839 are from Institut National d'Études Démographiques (1977, pp. 332–333). CBR, CMR, CDR 1840–1914 are from Mitchell (1981, pp. 116, 119, 125). The event and rate series are spliced after detrending.

Infant mortality rate 1740–1829 is from Institut National d'Études Démographiques (1977, pp. 332–333). Infant mortality rate 1830–1914 is from Mitchell (1981, pp. 137, 138, 149). Infant mortality rate before 1740 is estimated to be 296, the average of 1740–1749.

Wheat prices 1486–1768 are from the following places: Douai 1486–1768 from Mestayer (1963, pp. 168–170); Paris 1486–1768 from Baulant (1968, pp. 537–549); Strasbourg 1486–1768 from Hanauer (1878, vol. 2, pp. 96–101); Toulouse 1486–1768 from Frêche and Frêche (1967, pp. 85–90); Grenoble 1501–1768 from Hauser (1936, pp. 365–370); Poitiers 1548–1768 from Raveau (1930, pp. 315–365); Aix 1580–1768 from Baehrel (1961, p. 535); Angers 1580–1768 from Hauser (1936, pp. 258–262); Pontoise 1641–1768 from Dupâquier *et al.* (1968, pp. 31–101); St. Etiene 1641–1768 from Gras (1910, pp. 266–292). Each series is detrended, then the annual averages are calculated for the period 1491–1763.

Wheat prices 1726–1913 are France wheat prices from Labrousse (1970, pp. 9–11). The four year gap in this series 1793–1796 is filled using data from Labrousse (1933, p. 105). France wheat price for 1914 is based on data from Fourastié (1958, vol. 1, p. 13). The detrended series is calculated for the period 1731–1909. The detrended series in the preceding paragraph is used from 1491–1730. The two detrended series are highly correlated, $r = 0.90$, where they overlap (1731–1763) and have similar coefficients of variation.

The monthly temperature data 1660–1914 are based on the following series. Paris 1757–1885 from Renou (1889, pp. B211–B213) and Paris 1886–1914 from Ministère de l'Économie et des Finances (1966, pp. 15–16). The means of the 1886–1914 data are adjusted to match the means of the earlier series based on the decadal period in which the two series overlap, 1876–1885. The data 1660–1756 are estimated using the Central England temperature series from Manley (1974, pp. 393–395) with estimates based on the decadal period in which the two series overlap, 1757–1766.

Prussia 1700–1914

Births, marriages, and deaths 1695–1757 are from Behre (1905, pp. 445–449). The series is based on data for the following regions of Prussia: Pommern-Camin-Lauenburg-Bütow, Neumark, Kurmark, Magdeburg-Mansfeld, and Halberstadt-Hohenstein. Some gaps in some series are filled based on the change in vital events of a neighboring region.

CBR, CMR, and CDR 1749–1805 are from Behre (1905, pp. 445–462). The series is based on data for the following regions of Prussia: Pommern-Camin-Lauenburg-Bütow, Neumark, Kurmark, Magdeburg-Mansfeld, Halberstadt-Hohenstein, Minden-Ravensberg-Tecklenburg-Lingen, Kleve-Mark-Mörs-Geldern, Schlesien, and Ostfriesland. The regions of Preussen und Litthauen (East Prussia) and Neufchatel are excluded because of complicated boundary changes and lack of data. Some gaps in some series are filled based on the change in vital events of a neighboring region. The sum of the vital events is calculated and divided by the population for each year. CBR, CMR, and CDR 1806–1815 are based on data for the city of Berlin from Statistischen Amt (1920, pp. 67, 70, 101), and for the city of Frankfurt from Bleicher (1895, p. 237). The annual estimates for Prussia for the years 1806–1815 are made by applying the average annual percent change in vital events in Berlin and Frankfurt during the period to the Prussia data beginning with 1805.

CBR, CMR, and CDR 1816–1914 are from Königlichen Statistischen Bureau (1904 vol. 188, pp. 12–13; and 1916, vol. 249, p. 14).

Deaths 1695–1815 probably include stillbirths which should be removed. This is accomplished by multiplying the number of births in a given year by 0.039, the estimated stillbirth rate in Prussia 1816–1870 from Königlichen Statistischen Bureau (1904, vol. 188, pp. 12–13), and subtracting this result from deaths.

The vital event and vital rate series are detrended and spliced.

Infant mortality rate 1695–1815 is estimated to be 188 which was the average rate in Prussia 1816–1870. Infant mortality rate 1816–1900 is from Königlichen Statistischen Bureau (1979, vol. 48, p. 97; and 1904, vol. 188, p. 121). Infant mortality rate is interpolated for 1867–1874 because infant mortality data were not collected during this period according to Königlichen Statistischen Bureau (1912, vol. 233, p. 414). Infant mortality rate 1901–1914 is from Königlichen Statistischen Bureau (various volumes).

Rye prices 1689–1825 are from the following: Berlin from Dieterici (1853, pp. 92–95) with gaps filled using Berlin rye prices from Naudé and Stalweit (1910, pp. 624–631), Stalweit (1931, pp. 647–651); Frankfurt rye prices are from Elsas (1949, vol. 2b, pp. 112–114) and Königlichen Statistischen Bureau (1905, p. 69); Danzig rye prices are from Furtak (1935, pp. 121–124) and Abel (1980, p. 308).

Each series is detrended, then the annual averages are calculated for the period 1694–1820.

Rye prices 1816–1903 are in marks per 1000 kg and are the average of Berlin, Rheinland, and Danzig rye prices Königlichen Statistischen Bureau (1905, p. 69).

Rye prices 1904–1914 are in marks per 1000 kg and are the average of Berlin, Frankfurt, and Danzig rye prices from Statistischen Reichsamt (1919, p. 96).

The monthly temperature data 1690–1914 are for Berlin and are based on the following: 1690–1699 is estimated based on Central England from Manley (1974, p. 393); 1700–1710 from Brumme (1981, p. 202); 1711–1768 from Hellmann (1910, pp. 57–61); 1769–1920 from Clayton (1927, pp. 501–503). Some gaps were filled in the 1711–1768 series using De Bilt, Netherlands, data from Labrijn (1945- 89, 94).

Sweden 1735–1914

CBR and CDR 1736–1914 are from Statistika Centralbyrån (1969, pp. 86–97). CBR and CDR for 1735 are based on data from Hofsten and Lundström (1976, p. 173). CMR 1755–1914 is from Statistika Centralbyrån (1969, pp. 90–97).

Male first marriage rate 1749 to 1875 is male first marriages multiplied by 1000 and divided by never married males aged 20 to 49. Female first marriage rate 1749 to 1875 is female first marriages multiplied by 1000 and divided by never married females aged 20 to 44. Data are from Sundbärg (1907, pp. 214–216).

Male remarriage rate 1749 to 1875 is male remarriages multiplied by 1000 and divided by widowed males aged 15 to 64. Female remarriage rate 1749 to 1875 is female remarriages multiplied by 1000 and divided by widowed females aged 15 to 54. Data are from Sundbärg (1907, pp. 218–220). Data 1751 to 1801 are estimated by Sundbärg (1907, p. 219).

Infant mortality rate 1735–1750 is estimated to be 205. The rate 205 is the average infant mortality rate 1751–1760 from Statistika Centralbyrån (1969, p. 91). Infant mortality rate 1751–1914 is from Statistika Centralbyrån (1969, pp. 90–97).

Rye prices 1721–1914 are in kronor per hectoliter and based on the following series: 1721–1731 is the average price of rye in Stockholm, Uppsala, Gotland, Halland, Varmland, and Orebro from Imhof (1976, pp. 754–761); 1732–1829 is Sweden rye from Jörberg (1972, vol. 1, pp. 632–634); 1830–1914 is Sweden rye from Myrdal (1933, pp. 174–175, 200, 202).

The monthly temperature data 1730–1914 are from the following series: 1730–1738 is estimated based on Berlin from Hellmann (1910, p. 57); 1739–1755 is for Uppsala from Hamberg (1906, p. 58); 1756–1914 is for Stockholm from Statistika Centralbyrån (1959, pp. 2–5).

APPENDIX TABLE I: England: means of the raw series and coefficients of variation of the detrended series

Place	Period	*n*	Mean of raw series				Coefficient of variation of detrended series				
			CBR	CMR	NDR	CDR	CBR	CMR	NDR	CDR	Grain prices
England	1550–1599	50	34.06	9.94	20.33	26.32	0.071	0.128	0.237	0.174	0.231
England	1560–1609	50	33.85	9.70	18.89	24.58	0.056	0.092	0.172	0.128	0.203
England	1570–1619	50	33.04	9.31	19.13	24.50	0.051	0.067	0.161	0.123	0.194
England	1580–1629	50	32.71	8.91	19.58	25.01	0.058	0.079	0.209	0.161	0.221
England	1590–1639	50	32.23	8.57	20.08	25.53	0.059	0.080	0.208	0.160	0.212
England	1600–1649	50	32.08	8.28	20.08	25.52	0.055	0.104	0.193	0.151	0.200
England	1610–1659	50	30.90	8.21	20.80	26.18	0.071	0.132	0.191	0.147	0.226
England	1620–1669	50	30.28	7.91	21.39	26.82	0.071	0.139	0.207	0.162	0.235
England	1630–1679	50	29.76	7.75	21.92	27.38	0.067	0.134	0.167	0.130	0.222
England	1640–1689	50	29.87	7.73	22.97	28.70	0.063	0.134	0.161	0.128	0.229
England	1650–1699	50	29.90	7.64	23.41	29.21	0.061	0.120	0.152	0.121	0.226
England	1660–1709	50	30.74	7.46	23.23	29.15	0.039	0.088	0.130	0.106	0.217
England	1670–1719	50	31.11	7.63	22.92	28.80	0.040	0.073	0.099	0.080	0.233
England	1680–1729	50	31.75	8.00	23.53	29.63	0.047	0.076	0.131	0.101	0.232
England	1690–1739	50	32.43	8.26	22.81	29.01	0.049	0.082	0.136	0.103	0.229
England	1700–1749	50	32.75	8.49	22.89	29.18	0.049	0.073	0.152	0.115	0.241
England	1710–1759	50	33.06	8.59	22.71	29.05	0.048	0.073	0.147	0.111	0.228
England	1720–1769	50	33.74	8.80	22.74	29.26	0.046	0.074	0.146	0.109	0.210
England	1730–1779	50	34.47	8.79	21.59	28.02	0.034	0.063	0.103	0.078	0.202
England	1740–1789	50	34.74	8.69	21.35	27.65	0.030	0.050	0.090	0.070	0.201
England	1750–1799	50	35.90	8.74	20.68	27.05	0.027	0.049	0.066	0.051	0.170
England	1760–1809	50	37.06	8.76	20.47	27.00	0.034	0.065	0.076	0.057	0.202
England	1770–1819	50	38.36	8.55	19.82	26.42	0.036	0.065	0.070	0.052	0.211
England	1780–1829	50	39.00	8.40	19.23	25.80	0.036	0.068	0.069	0.050	0.208
England	1790–1839	50	38.80	8.21	18.37	24.70	0.035	0.067	0.067	0.049	0.214
England	1800–1849	50	38.10	8.10	17.95	24.01	0.034	0.066	0.065	0.049	0.212
England	1810–1859	50	37.45	8.12	17.44	23.30	0.024	0.047	0.058	0.045	0.196
England	1820–1869	50	36.52	8.16	17.03	22.64	0.019	0.043	0.054	0.043	0.186
England	1830–1879	50	35.78	8.18	16.81	22.26	0.016	0.042	0.052	0.042	0.180
England	1840–1889	50	35.21	8.08	16.37	21.67	0.014	0.041	0.050	0.042	0.165
England	1850–1899	50	34.15	8.04	15.61	20.75	0.013	0.039	0.046	0.040	0.164
England	1860–1909	50	32.47	7.90	14.70	19.46	0.012	0.037	0.040	0.037	0.116
England	1670–1909	240	34.36	8.20	19.56	25.44	0.033	0.061	0.091	0.070	0.195

Place	Period	n	Mean of raw temperature series					Coefficient of variation of detrended temperature series				
			Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
England	1670–1719	50	38.22	51.40	58.26	43.01	47.72	0.059	0.022	0.022	0.036	0.017
England	1680–1729	50	38.46	51.58	58.47	43.43	47.99	0.059	0.023	0.020	0.033	0.017
England	1690–1739	50	39.12	51.83	58.86	43.73	48.39	0.050	0.020	0.019	0.028	0.015
England	1700–1749	50	39.22	52.10	59.34	43.96	48.66	0.054	0.022	0.018	0.036	0.019
England	1710–1759	50	39.35	52.08	59.27	43.85	48.64	0.054	0.022	0.018	0.036	0.020
England	1720–1769	50	39.26	52.19	59.28	43.70	48.60	0.054	0.023	0.017	0.037	0.020
England	1730–1779	50	39.18	52.12	59.34	43.67	48.58	0.056	0.023	0.016	0.035	0.021
England	1740–1789	50	38.47	52.08	59.22	43.10	48.22	0.058	0.026	0.018	0.036	0.023
England	1750–1799	50	38.85	52.27	59.11	43.00	48.31	0.057	0.029	0.018	0.033	0.020
England	1760–1809	50	38.78	52.36	59.23	43.03	48.35	0.053	0.028	0.018	0.035	0.020
England	1770–1819	50	38.85	52.19	59.01	42.98	48.26	0.058	0.028	0.020	0.039	0.021
England	1780–1829	50	38.91	52.27	58.88	43.14	48.30	0.059	0.028	0.022	0.042	0.023
England	1790–1839	50	39.16	52.18	58.75	43.62	48.43	0.059	0.027	0.023	0.040	0.023
England	1800–1849	50	39.11	52.27	58.53	43.71	48.40	0.055	0.024	0.024	0.039	0.022
England	1810–1859	50	39.17	52.14	58.45	43.86	48.41	0.058	0.024	0.025	0.039	0.024
England	1820–1869	50	39.35	52.35	58.58	44.09	48.59	0.055	0.024	0.026	0.037	0.023
England	1830–1879	50	39.56	52.16	58.57	43.68	48.49	0.053	0.025	0.024	0.037	0.022
England	1840–1889	50	39.57	51.96	58.52	43.43	48.37	0.053	0.023	0.024	0.037	0.021
England	1850–1899	50	39.67	51.88	58.70	43.44	48.42	0.055	0.024	0.023	0.039	0.021
England	1860–1909	50	39.71	51.79	58.58	43.53	48.40	0.052	0.023	0.023	0.037	0.019
England	1670–1909	240	39.04	51.96	58.75	43.44	48.30	0.056	0.024	0.021	0.037	0.020

Notes: NDR is the non-infant death rate.
Temperature is in degrees Fahrenheit.

APPENDIX TABLE II: France: means of the raw series and coefficients of variation of the detrended series

Place	Period	n	Mean of raw series				Coefficient of variation of detrended series				
			CBR*	CMR	NDR*	CDR*	CBR*	CMR	NDR*	CDR*	Grain prices
France	1570–1619	50	911806		403539	673433	0.080		0.413	0.236	0.166
France	1580–1629	50	918524		390575	662458	0.072		0.404	0.231	0.135
France	1590–1639	50	932881		418323	694455	0.064		0.352	0.209	0.148
France	1600–1649	50	960031		375575	659744	0.050		0.316	0.183	0.163
France	1610–1659	50	953205		381138	663287	0.058		0.359	0.204	0.185
France	1620–1669	50	952894		386508	668565	0.064		0.380	0.215	0.204
France	1630–1679	50	956878		416514	699750	0.062		0.385	0.218	0.205
France	1640–1689	50	962686		414660	699615	0.056		0.308	0.168	0.193
France	1650–1699	50	955530		478285	761122	0.071		0.373	0.214	0.215
France	1660–1709	50	985709		498339	790108	0.069		0.325	0.192	0.259
France	1670–1719	50	976987		510770	799958	0.077		0.336	0.200	0.265
France	1680–1729	50	977609		506918	796290	0.077		0.331	0.197	0.269
France	1690–1739	50	990616		520470	813692	0.075		0.330	0.197	0.259
France	1700–1749	50	998715		545995	841057	0.062		0.245	0.146	0.250
France	1710–1759	50	993378		571223	861431	0.056		0.233	0.141	0.181
France	1720–1769	50	1014694		602164	895459	0.033		0.153	0.098	0.156
France	1730–1779	50	1017103		632295	922030	0.030		0.150	0.100	0.146
France	1740–1789	50	1016682		661786	946780	0.028		0.140	0.095	0.151
France	1750–1799	50	38.39	8.67	24.49	34.95	0.026	0.094	0.136	0.096	0.123
France	1760–1809	50	36.84	8.41	24.15	33.76	0.026	0.099	0.134	0.095	0.134
France	1770–1819	50	35.55	8.39	23.61	32.31	0.030	0.141	0.142	0.103	0.177
France	1780–1829	50	34.36	8.33	22.77	30.57	0.028	0.137	0.123	0.091	0.182
France	1790–1839	50	32.61	8.21	21.55	28.30	0.027	0.134	0.124	0.094	0.186
France	1800–1849	50	30.75	7.91	20.58	26.35	0.026	0.119	0.094	0.075	0.196
France	1810–1859	50	29.51	7.99	19.93	25.21	0.028	0.114	0.090	0.076	0.224
France	1820–1869	50	28.26	7.95	19.18	24.09	0.021	0.039	0.068	0.062	0.199
France	1830–1879	50	27.08	7.99	19.27	23.92	0.028	0.062	0.104	0.093	0.194
France	1840–1889	50	26.01	7.85	18.95	23.36	0.027	0.060	0.099	0.089	0.185
France	1850–1899	50	24.94	7.74	18.71	22.97	0.025	0.058	0.095	0.086	0.170
France	1860–1909	50	23.80	7.69	18.21	22.14	0.022	0.056	0.088	0.079	0.110
France	1670–1909	240	30.69	8.08**	20.99**	27.57**	0.042	0.091**	0.186	0.120	0.188

Place	Period	n	Mean of raw temperature series					Coefficient of variation of detrended temperature series				
			Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
France	1670–1719	50	38.34	57.35	64.91	43.33	50.98	0.059	0.022	0.022	0.036	0.017
France	1680–1729	50	38.58	57.55	65.15	43.76	51.26	0.059	0.023	0.020	0.033	0.016
France	1690–1739	50	39.24	57.83	65.59	44.05	51.68	0.050	0.020	0.019	0.028	0.014
France	1700–1749	50	39.34	58.13	66.12	44.29	51.97	0.054	0.022	0.018	0.036	0.018
France	1710–1759	50	39.44	58.12	66.02	44.13	51.93	0.054	0.022	0.019	0.036	0.019
France	1720–1769	50	39.50	58.24	66.04	44.08	51.97	0.053	0.024	0.018	0.039	0.019
France	1730–1779	50	39.52	57.88	65.90	44.31	51.90	0.056	0.025	0.017	0.040	0.021
France	1740–1789	50	38.81	57.28	65.10	43.53	51.18	0.062	0.029	0.022	0.050	0.025
France	1750–1799	50	39.05	56.85	64.26	43.43	50.90	0.061	0.032	0.021	0.049	0.023
France	1760–1809	50	39.02	56.39	63.77	43.64	50.71	0.061	0.033	0.020	0.052	0.024
France	1770–1819	50	38.91	55.84	62.91	43.58	50.31	0.066	0.033	0.022	0.053	0.026
France	1780–1829	50	38.68	55.74	62.47	43.45	50.08	0.069	0.033	0.023	0.058	0.027
France	1790–1839	50	38.81	55.64	62.48	44.11	50.26	0.067	0.032	0.023	0.051	0.025
France	1800–1849	50	38.73	55.90	62.46	44.07	50.29	0.065	0.031	0.025	0.050	0.025
France	1810–1859	50	38.65	55.85	62.36	43.97	50.21	0.064	0.029	0.027	0.050	0.026
France	1820–1869	50	38.74	56.04	62.52	44.03	50.33	0.060	0.030	0.028	0.050	0.025
France	1830–1879	50	39.06	55.84	62.47	43.52	50.22	0.054	0.029	0.026	0.055	0.024
France	1840–1889	50	39.03	55.75	62.34	43.25	50.09	0.052	0.026	0.026	0.054	0.024
France	1850–1899	50	39.20	55.71	62.50	43.37	50.20	0.057	0.025	0.024	0.053	0.023
France	1860–1909	50	39.24	55.74	62.49	43.45	50.23	0.058	0.025	0.023	0.052	0.021
France	1670–1909	240	38.92	56.64	63.83	43.68	50.77	0.059	0.027	0.022	0.046	0.022

* Vital events are used from 1570–1619 to 1740–1789. Vital rates are used from 1750–1799 to 1860–1909.
** 1750–1909.

Notes: NDR is the non-infant death rate.
Temperature is in degrees Fahrenheit.
Blanks indicate the data are not available.

APPENDIX TABLE III: Prussia: means of the raw series and coefficients of variation of the detrended series

Place	Period	n	Mean of raw series				Coefficient of variation of detrended series				
			CBR*	CMR*	NDR*	CDR*	CBR*	CMR*	NDR*	CDR*	Grain prices
Central Prussia	1700–1749	50	45222	11882	24091	32593	0.049	0.069	0.139	0.098	0.230
Central Prussia	1710–1759	50	48652	12717	29237	38383	0.060	0.089	0.160	0.116	0.225
Central Prussia	1720–1769	50	51755	13406	31998	41728	0.062	0.101	0.172	0.124	0.299
Central Prussia	1730–1779	50	53842	13740	34830	44953	0.066	0.104	0.212	0.154	0.306
Central Prussia	1740–1789	50	55949	13792	35445	45963	0.063	0.098	0.204	0.149	0.295
Central Prussia	1750–1799	50	59157	14205	36482	47604	0.060	0.090	0.201	0.147	0.290
Prussia	1760–1809	50	40.90	9.18	24.16	31.92	0.042	0.080	0.145	0.108	0.214
Prussia	1770–1819	50	40.82	8.89	23.30	30.98	0.042	0.092	0.135	0.108	0.223
Prussia	1780–1829	50	41.19	8.93	22.17	29.79	0.036	0.088	0.099	0.085	0.208
Prussia	1790–1839	50	40.98	9.05	22.21	29.74	0.036	0.091	0.103	0.089	0.224
Prussia	1800–1849	50	40.55	8.98	21.92	29.35	0.041	0.092	0.102	0.087	0.248
Prussia	1810–1859	50	39.51	8.98	21.12	28.34	0.047	0.095	0.098	0.083	0.261
Prussia	1820–1869	50	38.73	8.87	20.39	27.69	0.042	0.063	0.097	0.074	0.234
Prussia	1830–1879	50	38.41	8.81	20.21	27.74	0.046	0.077	0.098	0.074	0.218
Prussia	1840–1889	50	38.31	8.59	19.19	26.89	0.044	0.071	0.089	0.066	0.209
Prussia	1850–1899	50	38.11	8.47	17.97	25.77	0.037	0.067	0.081	0.061	0.183
Prussia	1860–1909	50	37.34	8.35	16.42	23.99	0.028	0.057	0.070	0.054	0.142
Prussia***	1700–1909	240	39.25**	8.84**	20.57**	28.09**	0.043	0.077	0.123	0.093	0.213

Place	Period	n	Mean of raw temperature series					Coefficient of variation of detrended temperature series				
			Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
Prussia	1700–1749	50	32.88	54.30	59.93	39.30	46.60	0.099	0.033	0.024	0.056	0.028
Prussia	1710–1759	50	33.92	54.96	60.82	39.69	47.35	0.100	0.032	0.026	0.049	0.029
Prussia	1720–1769	50	34.09	55.19	61.31	39.61	47.55	0.098	0.030	0.024	0.048	0.026
Prussia	1730–1779	50	34.02	55.30	61.90	39.76	47.75	0.103	0.032	0.023	0.053	0.029
Prussia	1740–1789	50	33.34	55.85	62.82	39.67	47.92	0.107	0.033	0.026	0.058	0.032
Prussia	1750–1799	50	33.75	56.41	63.47	39.39	48.26	0.108	0.034	0.027	0.062	0.031
Prussia	1760–1809	50	33.01	56.03	63.58	39.40	48.01	0.098	0.035	0.026	0.070	0.031
Prussia	1770–1819	50	32.73	55.81	63.34	39.26	47.79	0.103	0.040	0.029	0.072	0.034
Prussia	1780–1829	50	32.51	55.92	63.29	39.30	47.76	0.106	0.040	0.028	0.077	0.034
Prussia	1790–1839	50	32.57	55.74	62.98	39.64	47.73	0.110	0.038	0.030	0.071	0.034
Prussia	1800–1849	50	32.21	55.58	62.55	39.77	47.53	0.105	0.034	0.030	0.069	0.032
Prussia	1810–1859	50	32.66	55.61	62.48	39.99	47.69	0.106	0.032	0.031	0.063	0.032
Prussia	1820–1869	50	33.21	55.79	62.71	40.45	48.04	0.105	0.028	0.030	0.063	0.032
Prussia	1830–1879	50	33.78	55.55	62.84	40.38	48.14	0.097	0.029	0.029	0.057	0.031
Prussia	1840–1889	50	33.97	55.53	62.90	40.46	48.22	0.093	0.032	0.025	0.055	0.029
Prussia	1850–1899	50	34.43	55.55	63.10	40.51	48.40	0.089	0.031	0.023	0.052	0.028
Prussia	1860–1909	50	34.78	55.71	63.00	40.66	48.54	0.085	0.031	0.022	0.053	0.026
Prussia	1700–1909	210	33.40	55.48	62.28	39.81	47.74	0.099	0.032	0.026	0.059	0.029

* Vital events are used from 1700–1749 to 1750–1799. Vital rates are used from 1760–1809 to 1860–1909.
** 1760–1909.
*** Includes Central Prussia data to 1759.

Notes: NDR is the non-infant death rate.
Temperature is in degrees Fahrenheit.

APPENDIX TABLE IV: Sweden: means of the raw series and coefficients of variation of the detrended series

Place	Period	n	Mean of raw series				Coefficient of variation of detrended series				
			CBR	CMR	NDR	CDR	CBR	CMR	NDR	CDR	Grain prices
Sweden	1740–1789	50	33.77		21.46	28.40	0.057		0.225	0.177	0.197
Sweden	1750–1799	50	33.78		20.44	27.30	0.055		0.199	0.159	0.193
Sweden	1760–1809	50	32.72	8.33	20.84	27.46	0.059	0.075	0.217	0.175	0.184
Sweden	1770–1819	50	32.49	8.38	20.88	27.27	0.063	0.091	0.216	0.172	0.147
Sweden	1780–1829	50	32.88	8.37	19.94	26.13	0.052	0.086	0.146	0.118	0.137
Sweden	1790–1839	50	32.71	8.23	19.35	25.35	0.053	0.089	0.143	0.117	0.144
Sweden	1800–1849	50	32.22	7.95	18.78	24.43	0.051	0.076	0.139	0.116	0.148
Sweden	1810–1859	50	32.62	7.88	17.80	23.18	0.044	0.075	0.113	0.097	0.147
Sweden	1820–1869	50	32.37	7.43	16.83	21.86	0.043	0.061	0.111	0.096	0.156
Sweden	1830–1879	50	31.52	7.10	16.14	20.82	0.040	0.062	0.102	0.091	0.147
Sweden	1840–1889	50	31.04	6.92	15.34	19.60	0.034	0.055	0.089	0.079	0.153
Sweden	1850–1899	50	30.28	6.66	14.89	18.75	0.032	0.053	0.087	0.078	0.159
Sweden	1860–1909	50	28.99	6.35	14.05	17.40	0.030	0.050	0.071	0.065	0.146
Sweden	1740–1909	170	31.81	7.52*	18.08	23.43	0.046	0.067*	0.153	0.123	0.161

Place	Period	n	Mean of raw series				Coefficient of variation of detrended series			
			First m.	First f.	Rem. m.	Rem. f.	First m.	First f.	Rem. m.	Rem. m.
Sweden	1760–1809	50	96.72	100.51	197.00	68.55	0.086	0.078	0.072	0.113
Sweden	1770–1819	50	94.29	97.95	177.97	66.31	0.100	0.090	0.090	0.139
Sweden	1780–1829	50	94.95	99.33	164.84	63.21	0.091	0.082	0.088	0.135
Sweden	1790–1839	50	95.89	101.01	153.65	60.45	0.092	0.085	0.095	0.137
Sweden	1800–1849	50	91.64	98.20	136.59	53.85	0.078	0.073	0.091	0.119
Sweden	1810–1859	50	88.99	96.87	123.46	49.45	0.076	0.072	0.093	0.112
Sweden	1820–1869	50	83.32	92.73	106.86	42.29	0.060	0.061	0.086	0.077
Sweden	1830–1879	50	78.17	87.31	94.84	37.76	0.064	0.064	0.084	0.079
Sweden	1840–1889	50	74.24	82.55	84.34	32.97	0.058	0.056	0.076	0.074
Sweden	1760–1889	130	88.07	94.34	141.69	52.31	0.077	0.072	0.081	0.104

Place	Period	n	Mean of raw temperature series					Coefficient of variation of detrended temperature series				
			Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
Sweden	1740–1789	50	25.30	48.80	59.03	34.68	41.95	0.158	0.038	0.035	0.066	0.038
Sweden	1750–1799	50	26.05	48.81	59.45	35.06	42.34	0.172	0.040	0.035	0.063	0.040
Sweden	1760–1809	50	25.25	48.60	59.71	35.27	42.21	0.161	0.040	0.035	0.069	0.037
Sweden	1770–1819	50	25.40	48.31	59.97	35.36	42.26	0.167	0.042	0.036	0.072	0.039
Sweden	1780–1829	50	25.91	48.34	59.76	35.43	42.36	0.163	0.043	0.035	0.075	0.039
Sweden	1790–1839	50	26.41	48.10	59.21	35.68	42.35	0.166	0.040	0.032	0.065	0.038
Sweden	1800–1849	50	25.86	47.78	59.04	35.58	42.07	0.148	0.040	0.032	0.066	0.035
Sweden	1810–1859	50	26.45	47.94	59.18	35.78	42.33	0.148	0.038	0.036	0.063	0.037
Sweden	1820–1869	50	26.32	47.78	58.67	35.84	42.15	0.142	0.038	0.035	0.062	0.038
Sweden	1830–1879	50	26.22	47.29	58.42	35.32	41.81	0.139	0.040	0.034	0.062	0.037
Sweden	1840–1889	50	26.45	47.44	58.57	35.19	41.91	0.136	0.041	0.032	0.065	0.037
Sweden	1850–1899	50	26.84	47.71	58.53	35.43	42.13	0.140	0.040	0.029	0.064	0.037
Sweden	1860–1909	50	27.24	47.48	57.98	35.49	42.05	0.133	0.044	0.028	0.059	0.036
Sweden	1740–1909	170	26.29	48.12	58.83	35.32	42.14	0.149	0.040	0.032	0.062	0.037

* 1760–1909

Notes: NDR is the non-infant death rate.
First m. is the male first marriage rate = (male first marriages × 1000)/(never married males aged 20 to 49).
First f. is the female first marriage rate = (female first marriages × 1000)/(never married females aged 20 to 44).
Rem m. is the male remarriage rate = (male remarriages × 1000)/(widowed males aged 15 to 64).
Rem f. is the female remarriage rate = (female remarriages × 1000)/(widowed females aged 15 to 54).
Temperature is in degrees Fahrenheit.
Blanks indicate the data are not available.

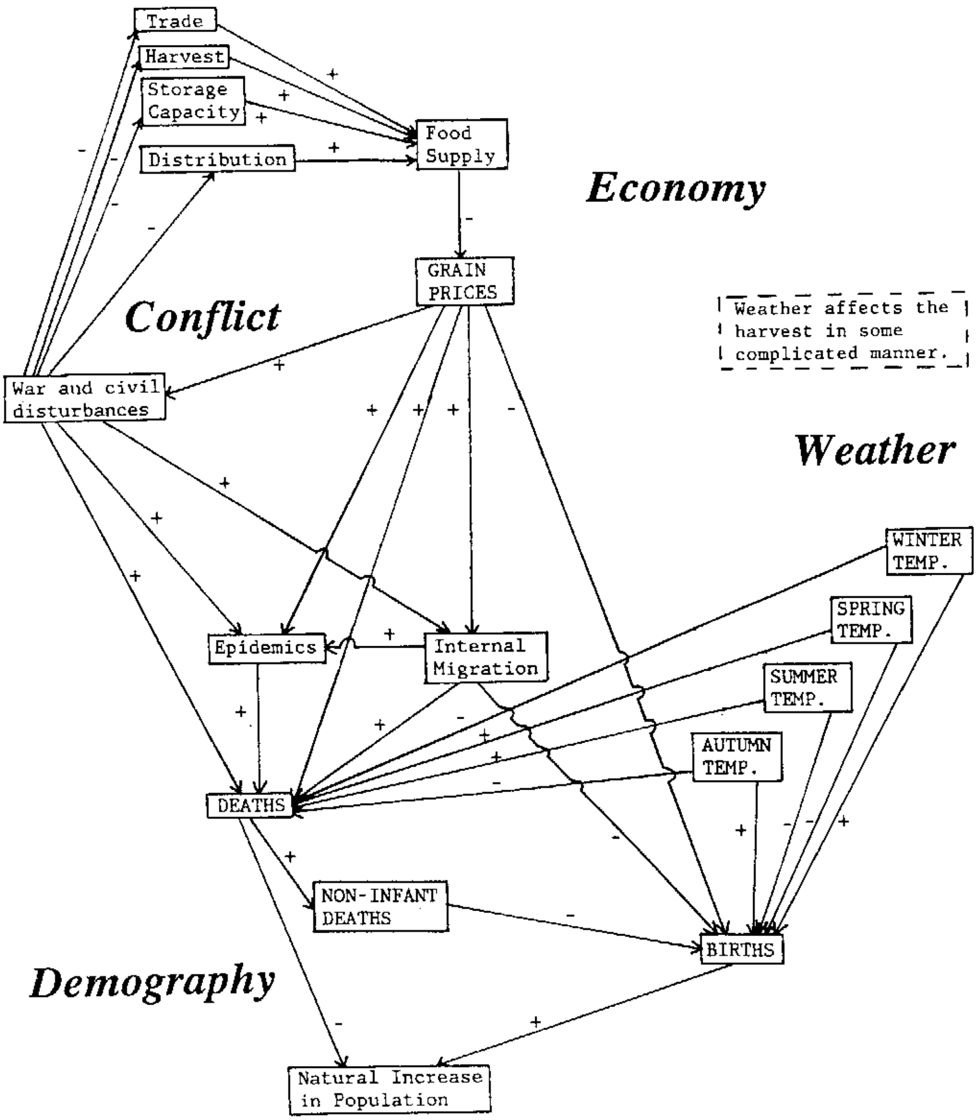
APPENDIX TABLE V: Estimation of distributed lag length using the Akaike AIC criterion

Equation	England*			France*			England		
	Period	Me-dian	Mean	Period	Me-dian	Mean	Period	Me-dian	Mean
Price lag lenth									
CBR = f(price)	1560–1719	2	3.2	1580–1719	6.5	6.1	1680–1909	1	1.9
CMR = f(price)	1560–1719	1	1.8				1680–1909	2	3.0
NDR = f(price)	1560–1719	4	4.0	1580–1719	9	7.1	1680–1909	3	3.6
CDR = f(price)	1560–1719	7	4.8	1580–1719	9	7.1	1680–1909	2	3.1
Non-infant mortality lag length									
CBR = f(NDR)	1560–1719	2	3.5	1580–1719	3.5	4.1	1680–1909	0	1.1
CMR = f(NDR)	1560–1719	2	2.8				1680–1909	2	2.2
Seasonal temperature lag length									
CBR = f(Winter temp.)							1680–1909	1	0.6
CBR = f(Spring temp.)							1680–1909	2	2.1
CBR = f(Summer temp.)							1680–1909	6	4.2
CBR = f(Autumn temp.)							1680–1909	2	3.2
NDR = f(Winter temp.)							1680–1909	2	1.8
NDR = f(Spring temp.)							1680–1909	5	4.0
NDR = f(Summer temp.)							1680–1909	0	1.2
NDR = f(Autumn temp.)							1680–1909	1	1.8
CDR = f(Winter temp.)							1680–1909	2	2.4
CDR = f(Spring temp.)							1680–1909	5	3.8
CDR = f(Summer temp.)							1680–1909	0	1.1
CDR = f(Autumn temp.)							1680–1909	1	1.8

* Includes plague years.

Notes: Determination of the distributed lag length is based on the Akaike AIC criterion (Judge *et al.*, 1988, p. 728). Lag lengths up to ten are tested. Ten years of data prior to the period shown above are necessary for this test.
The lag lengths are based on regressions run every ten years using 50 year intervals in the period shown.
0 indicates lag 0; 1 indicates lags 0 and 1; 2 indicates lags 0,1 and 2; and so on.
The trend has been removed from each series by dividing each data point, call it x, in a series by an eleven year average of data point centered around x.
NDR is the non-infant death rate.
In France from 1570 to 1739 vital events are used in place of vital rates.
In Prussia from 1700 to 1749 vital events are used in place of vital rates.

France			Prussia			Sweden		
Period	Me-dian	Mean	Period	Me-dian	Mean	Period	Me-dian	Mean
1680–1909	2	2.8	1710–1909	3	3.4	1750–1909	3	2.6
1760–1909	2	3.5	1710–1909	1	2.7	1770–1909	1	2.2
1680–1909	3	4.2	1710–1909	7	5.7	1750–1909	1	1.3
1680–1909	3	3.8	1710–1909	6.5	5.4	1750–1909	1	1.4
1680–1909	2	3.7	1710–1909	2	3.2	1750–1909	2	4.1
1760–1909	4	4.1	1710–1909	3	4.9	1770–1909	2.5	3.6
1680–1909	0	1.6	1710–1909	0	1.4	1750–1909	1	2.6
1680–1909	0	1.8	1710–1909	2	2.6	1750–1909	2	3.2
1680–1909	0	0.8	1710–1909	5	4.0	1750–1909	0	3.2
1680–1909	0	1.9	1710–1909	2	2.1	1750–1909	2	2.4
1680–1909	2	2.9	1710–1909	0	2.5	1750–1909	1.5	2.2
1680–1909	1	2.3	1710–1909	0	0.8	1750–1909	0	1.7
1680–1909	0	0.8	1710–1909	2	2.5	1750–1909	0	1.3
1680–1909	0	1.0	1710–1909	1.5	1.6	1750–1909	0.5	2.0
1680–1909	2	2.8	1710–1909	0	1.9	1750–1909	1	1.5
1680–1909	1	2.2	1710–1909	0	0.9	1750–1909	0	1.7
1680–1909	0	1.4	1710–1909	2	1.9	1750–1909	0	1.3
1680–1909	0	0.9	1710–1909	1	1.9	1750–1909	0.5	2.5



Notes: Only the important "causal" links are shown.
Variables used in the analysis are designated by all capital letters.
See text for details.

Fig. 1. A summary model of factors affecting annual variations in births and deaths for most of the population in a preindustrial society.

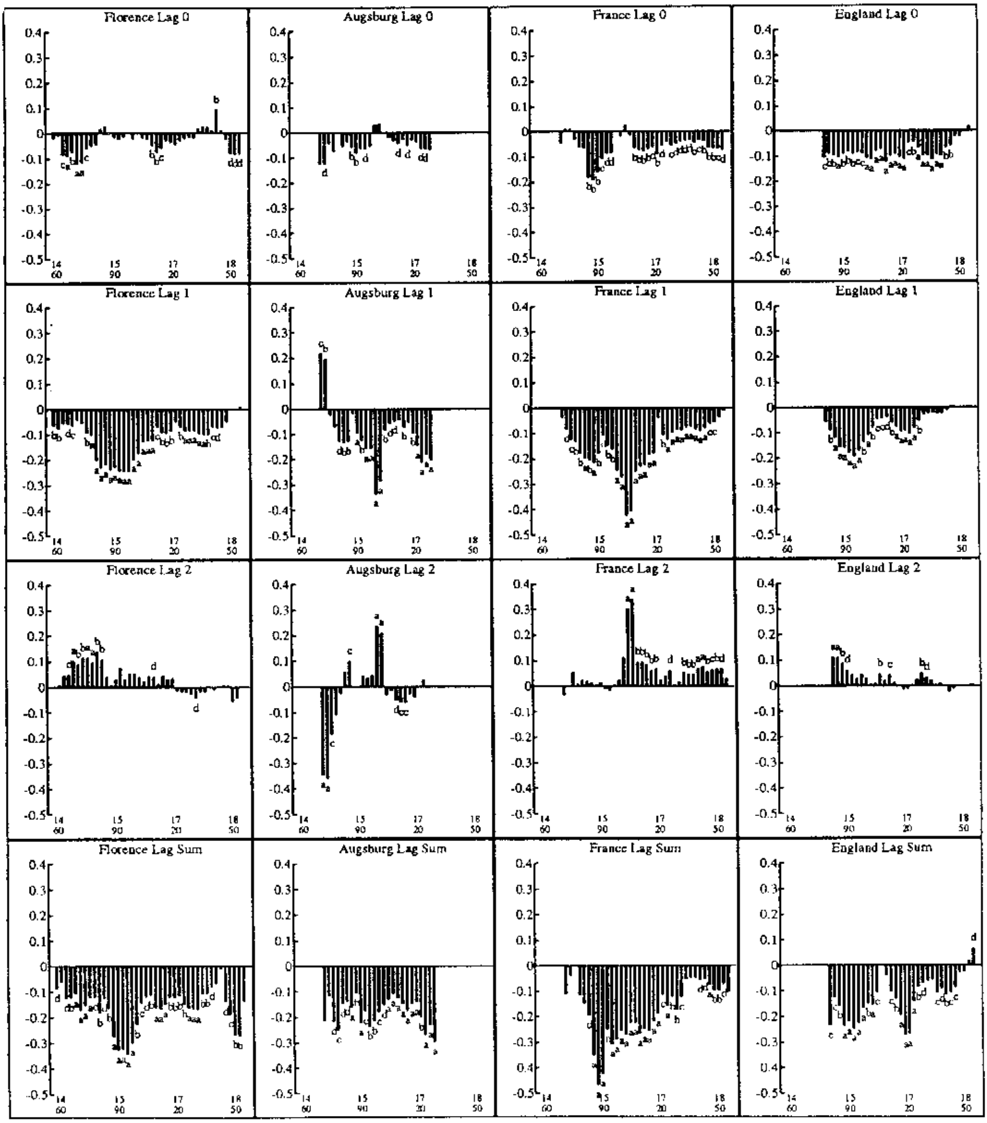


Fig. 2. Changes in the short-term preventive check over time in Florence, Augsburg, France, and England. The response of fertility to an increase in prices is shown. The vertical axis is elasticity. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation A.

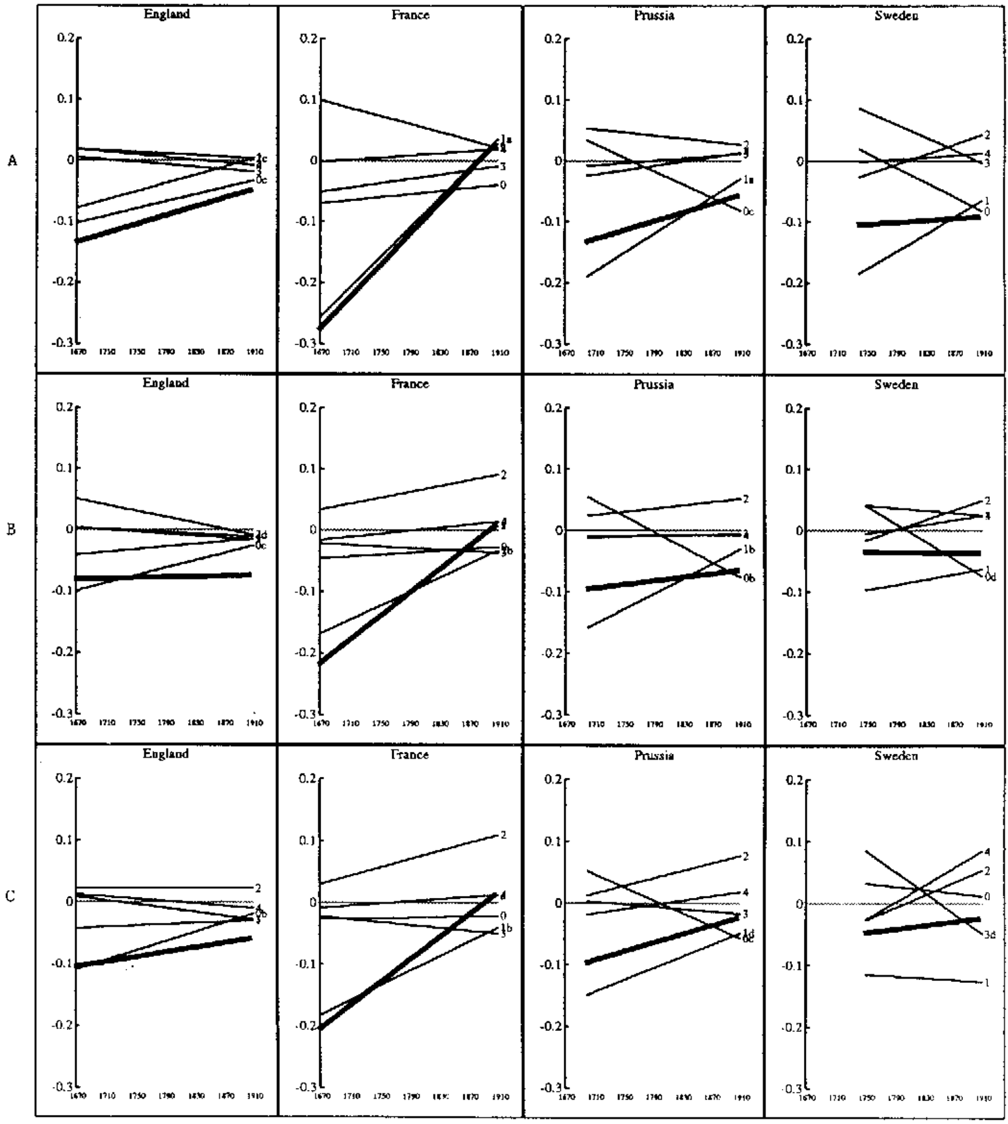


Fig. 3a. Changes in the short-term preventive check over time in England, France, Prussia and Sweden. Row A is the response of fertility to an increase in prices. Row B is the response of fertility to an increase in prices independent of non-infant mortality effects. Row C is the response of fertility to an increase in prices independent of non-infant mortality and temperature effects. The vertical axis is elasticity. The number to the right of the line is the lag. The thick black line is the lag sum. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations AA, BB, and DD.

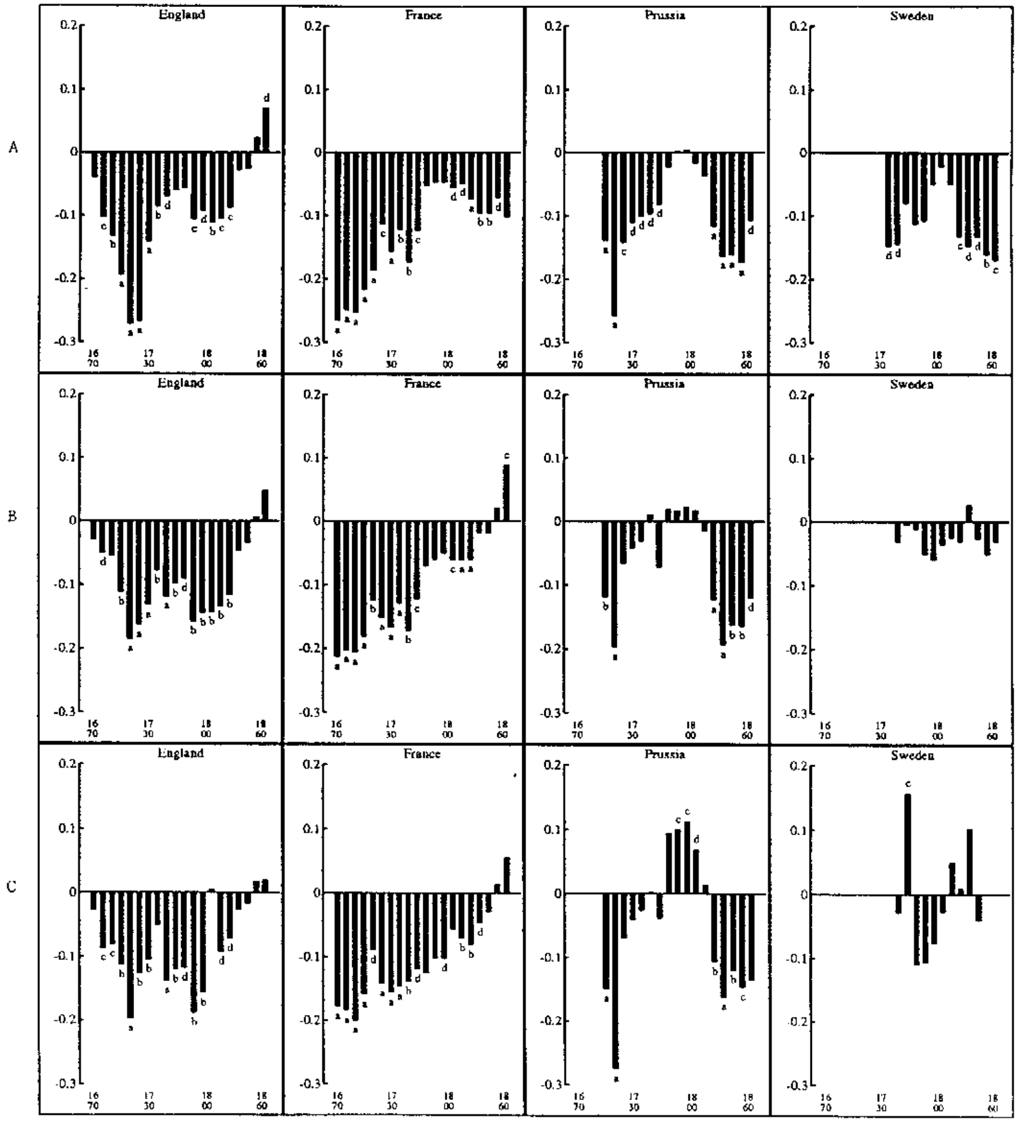


Fig. 3b. Changes in the short-term preventive check over time in England, France, Prussia and Sweden. Row A is the lag sum response of fertility to an increase in prices. Row B is the lag sum response of fertility to an increase in prices independent of non-infant mortality effects. Row C is the lag sum response of fertility to an increase in prices independent of non-infant mortality and temperature effects. The vertical axis is elasticity. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations A, B, and D.

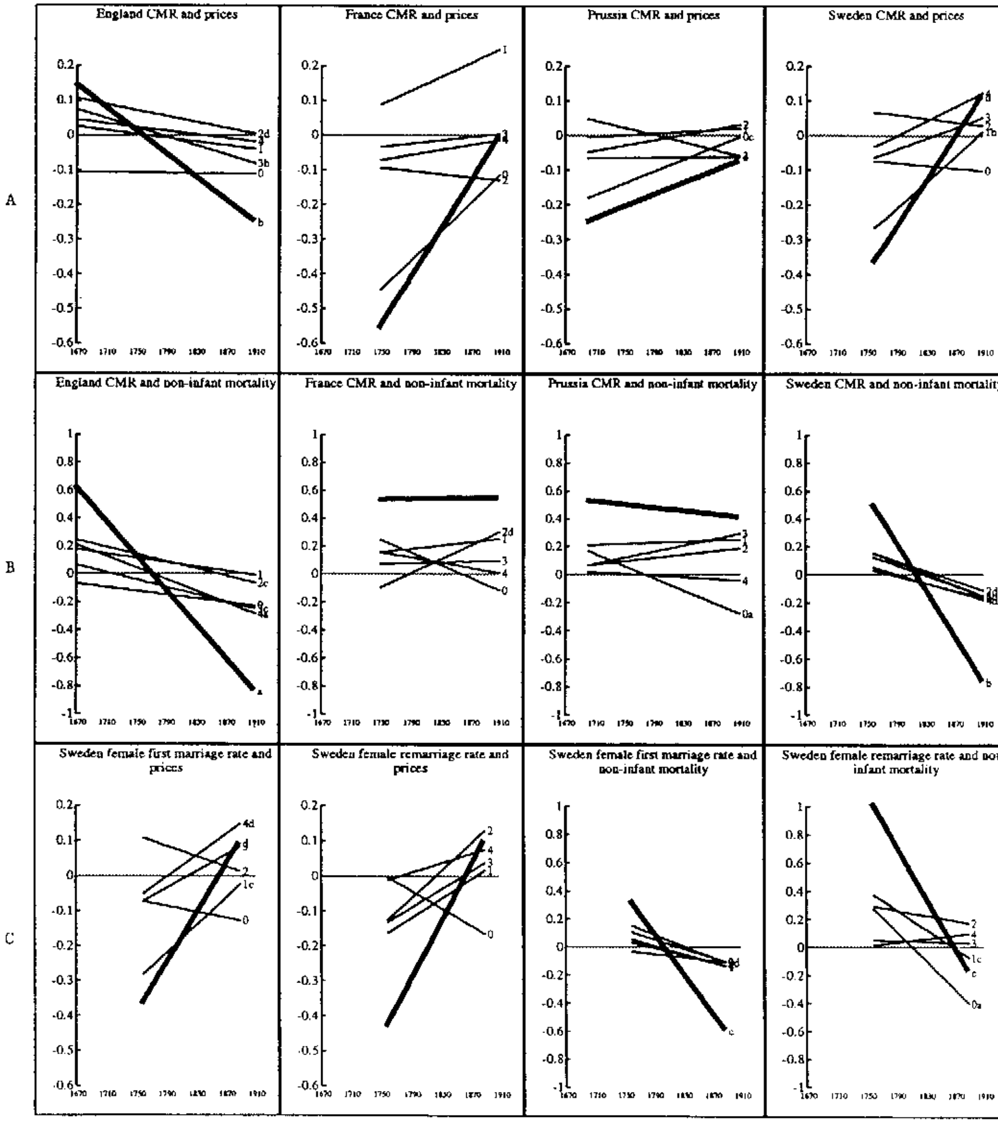


Fig. 4a. Changes in nuptiality response to prices and non-infant mortality over time in England, France, Prussia and Sweden. Row A is the response of nuptiality to an increase in prices independent of non-infant mortality effects. Row B is the response of nuptiality to an increase in non-infant mortality independent of price effects. Row C is the response of Sweden female first and remarriage rates to an increase in prices independent of non-infant mortality effects and to non-infant mortality independent of price effects. The vertical axis is elasticity. The number to the right of the line is the lag. The thick black line is the lag sum. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation EE.

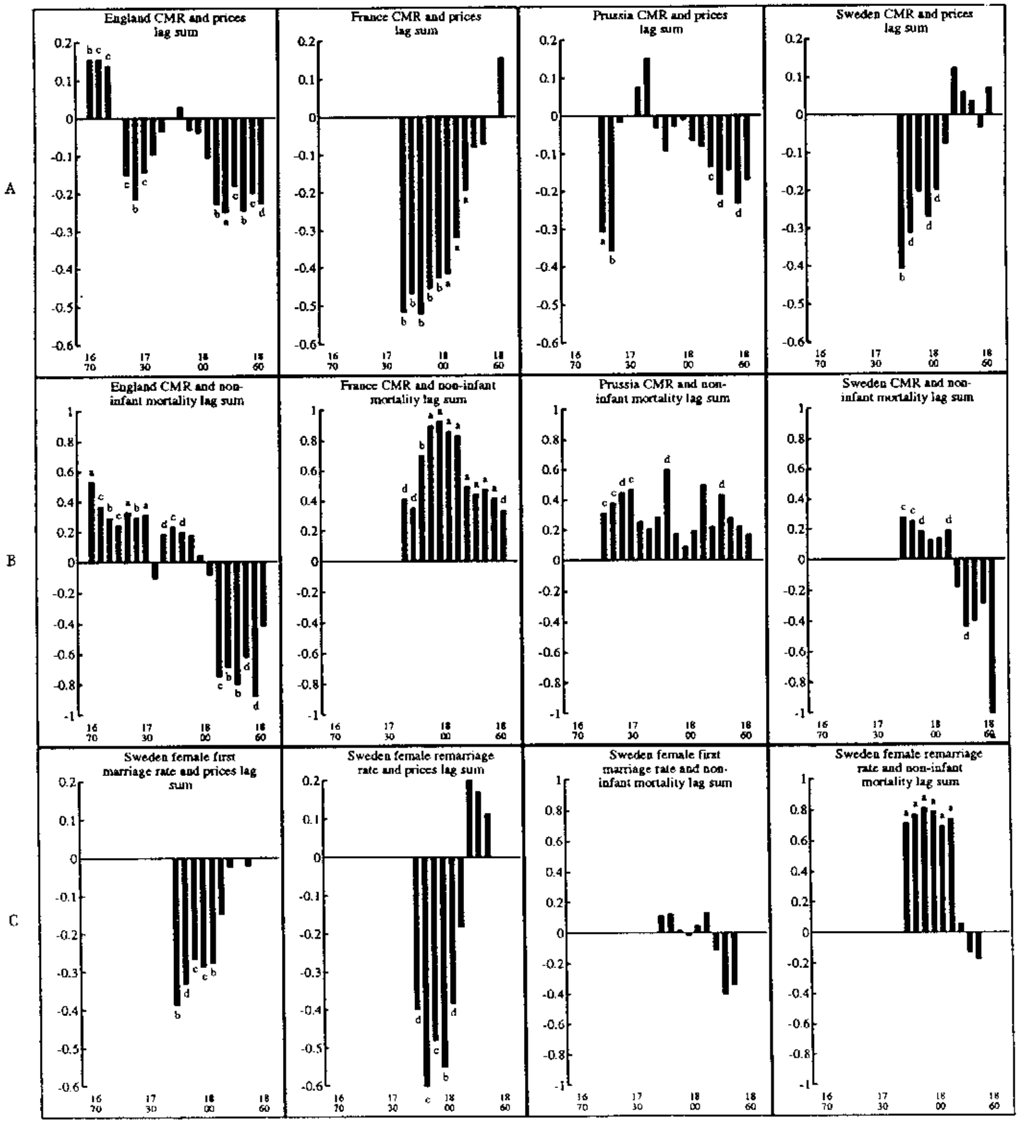


Fig. 4b. Changes in nuptiality response to prices and non-infant mortality over time in England, France, Prussia and Sweden. Row A is the lag sum response of nuptiality to an increase in prices independent of non-infant mortality effects. Row B is the lag sum response of nuptiality to an increase in non-infant mortality independent of price effects. Row C is the lag sum response of Sweden female first and remarriage rates to an increase in prices independent of non-infant mortality effects and to non-infant mortality independent of price effects. The vertical axis is elasticity. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation E.

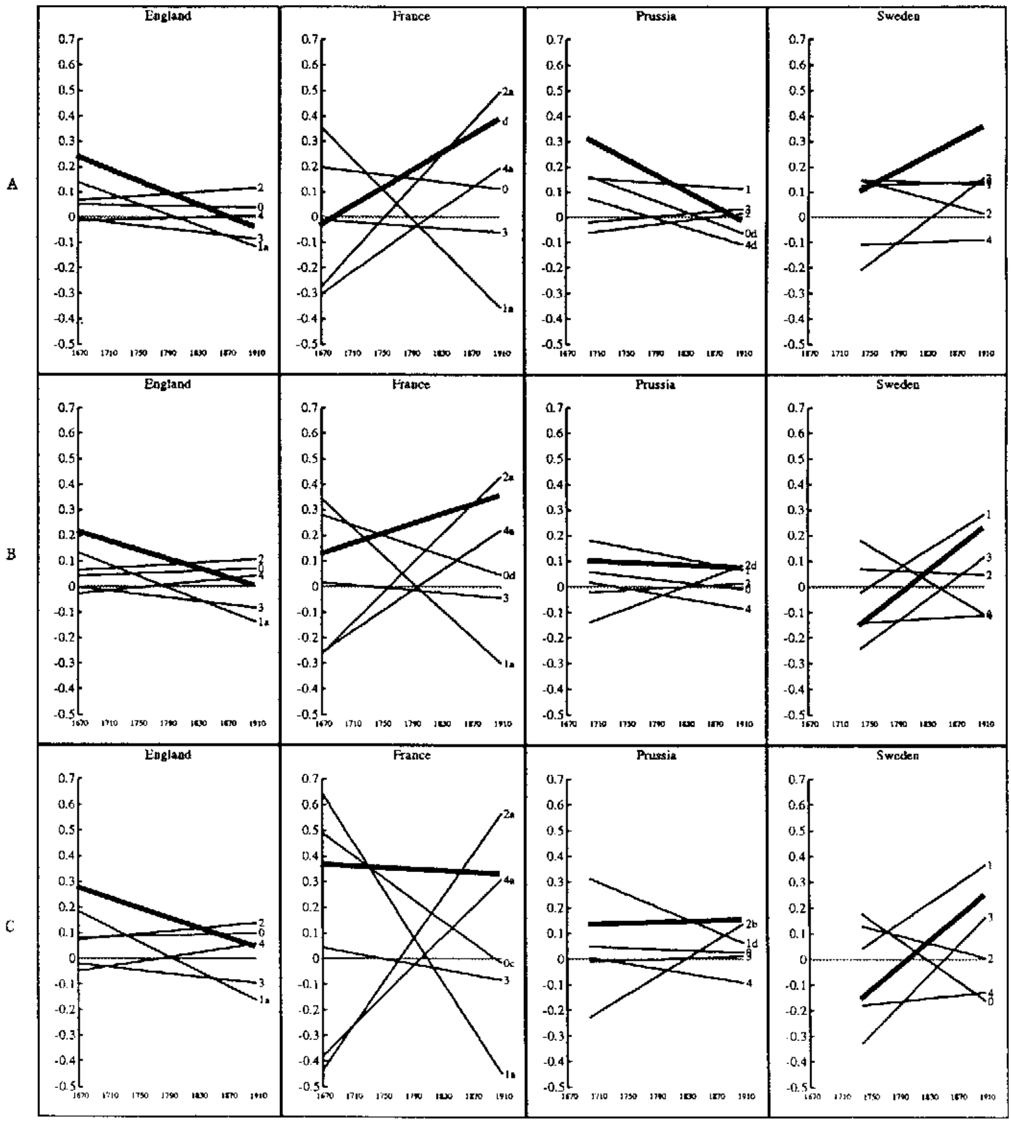


Fig. 5a. Changes in short-term positive check over time in England, France, Prussia and Sweden. Row A is the response of mortality to an increase in prices. Row B is the response of mortality to an increase in prices independent of temperature effects. Row C is the response of non-infant mortality to an increase in prices independent of temperature effects. The vertical axis is elasticity. The number to the right of the line is the lag. The thick black line is the lag sum. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations FF, GG, and II.

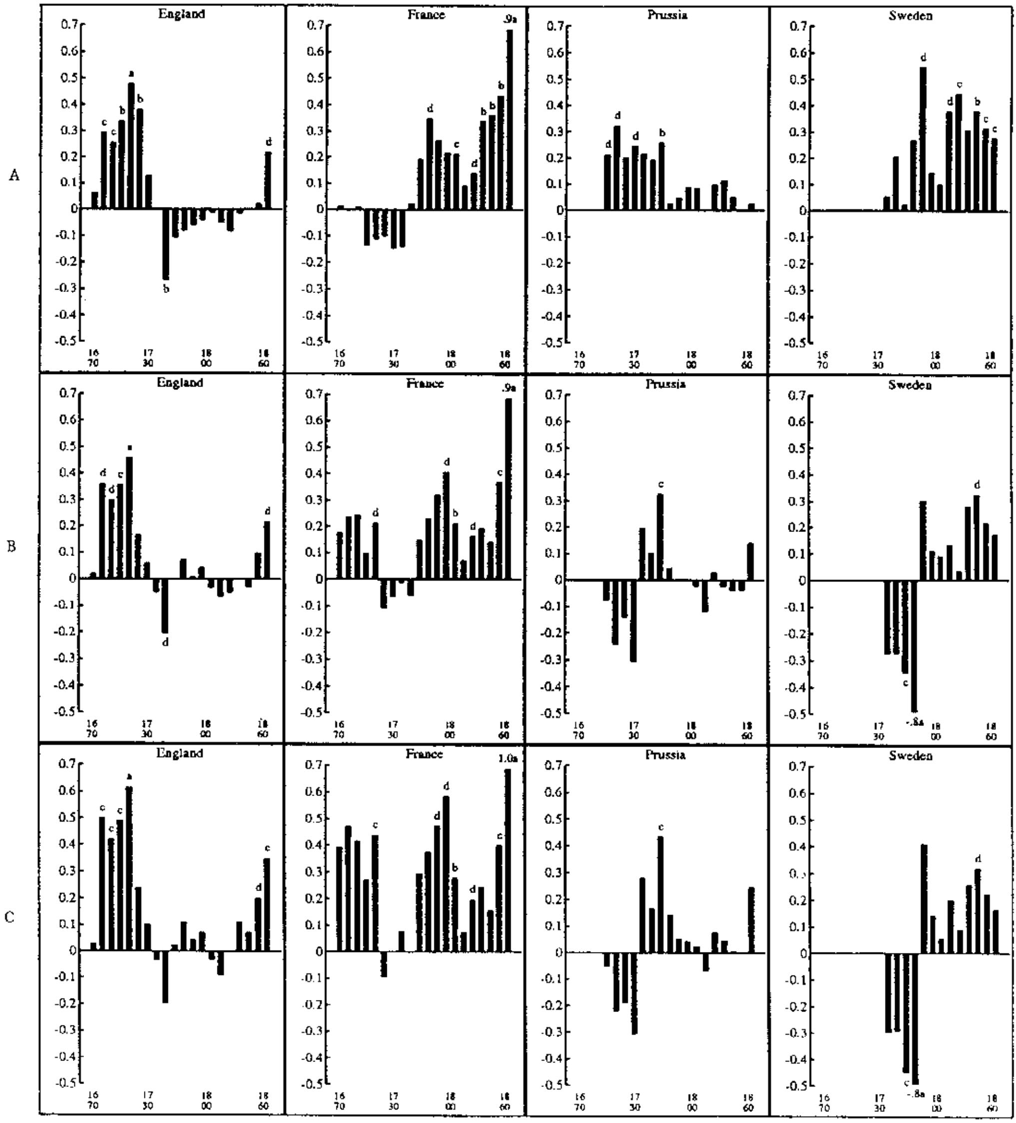


Fig. 5b. Changes in the short-term positive check over time in England, France, Prussia and Sweden. Row A is the lag sum response of mortality to an increase in prices. Row B is the lag sum response of mortality to an increase in prices independent of temperature effects. Row C is the lag sum response of non-infant mortality to an increase in prices independent of temperature effects. The vertical axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations F, G, and I.

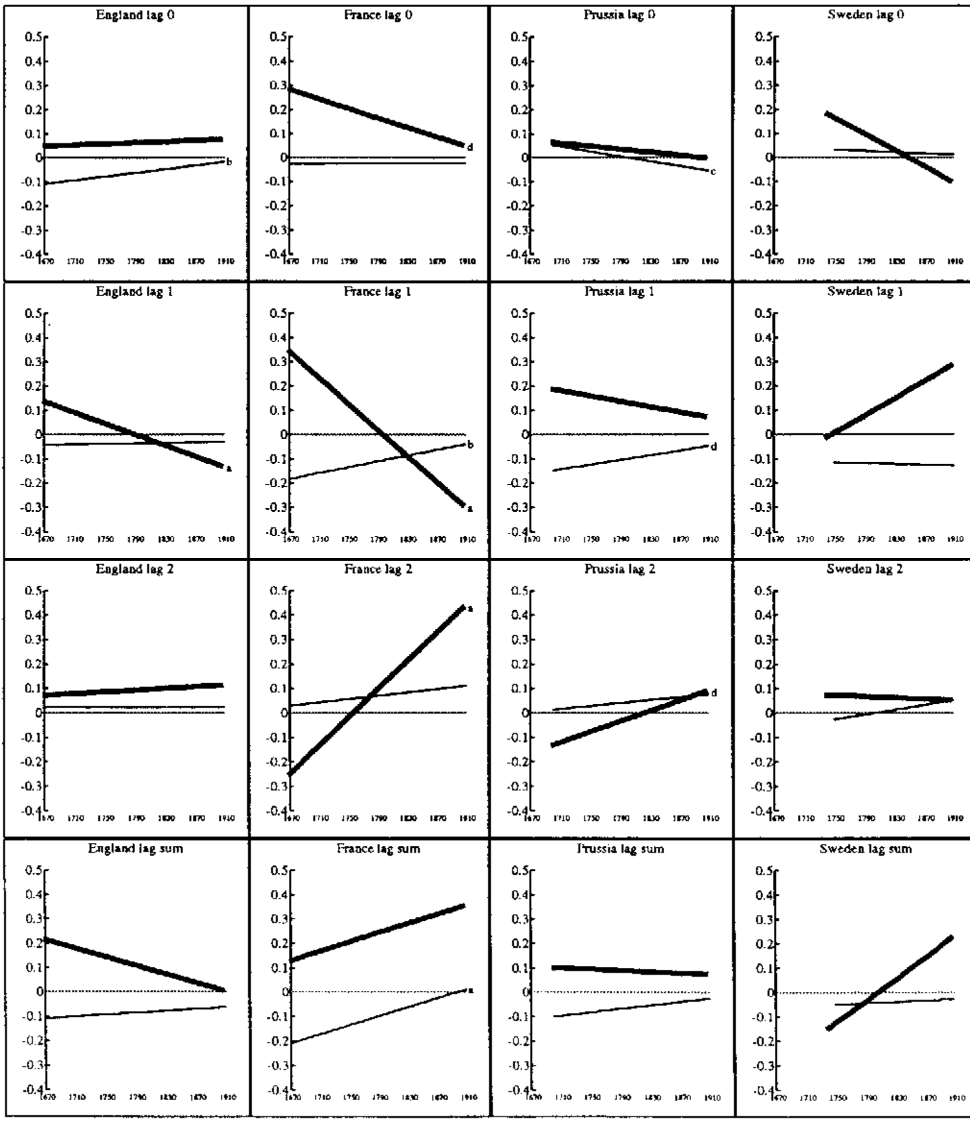


Fig. 6a. Changes in the short-term preventive and positive checks over time in England, France, Prussia and Sweden. The thin black line is the response of fertility to an increase in prices independent of non-infant mortality and temperature effects. The thick black line is the response of mortality to an increase in prices independent of temperature effects. The vertical axis is elasticity. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations DD and GG.

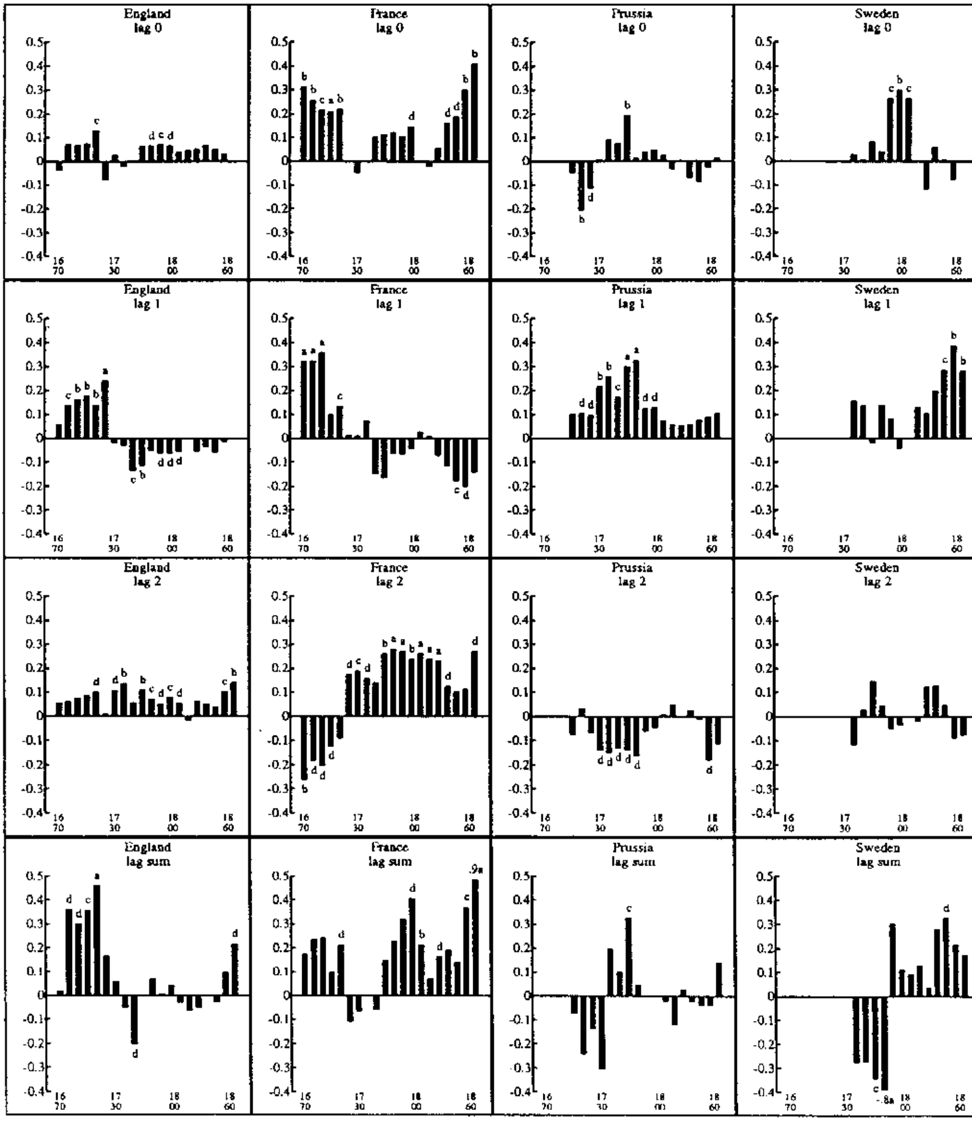


Fig. 6b. Changes in the short-term positive check over time in England, France, Prussia and Sweden. The response of mortality to an increase in prices independent of temperature effects is shown. The vertical axis is elasticity. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation G.

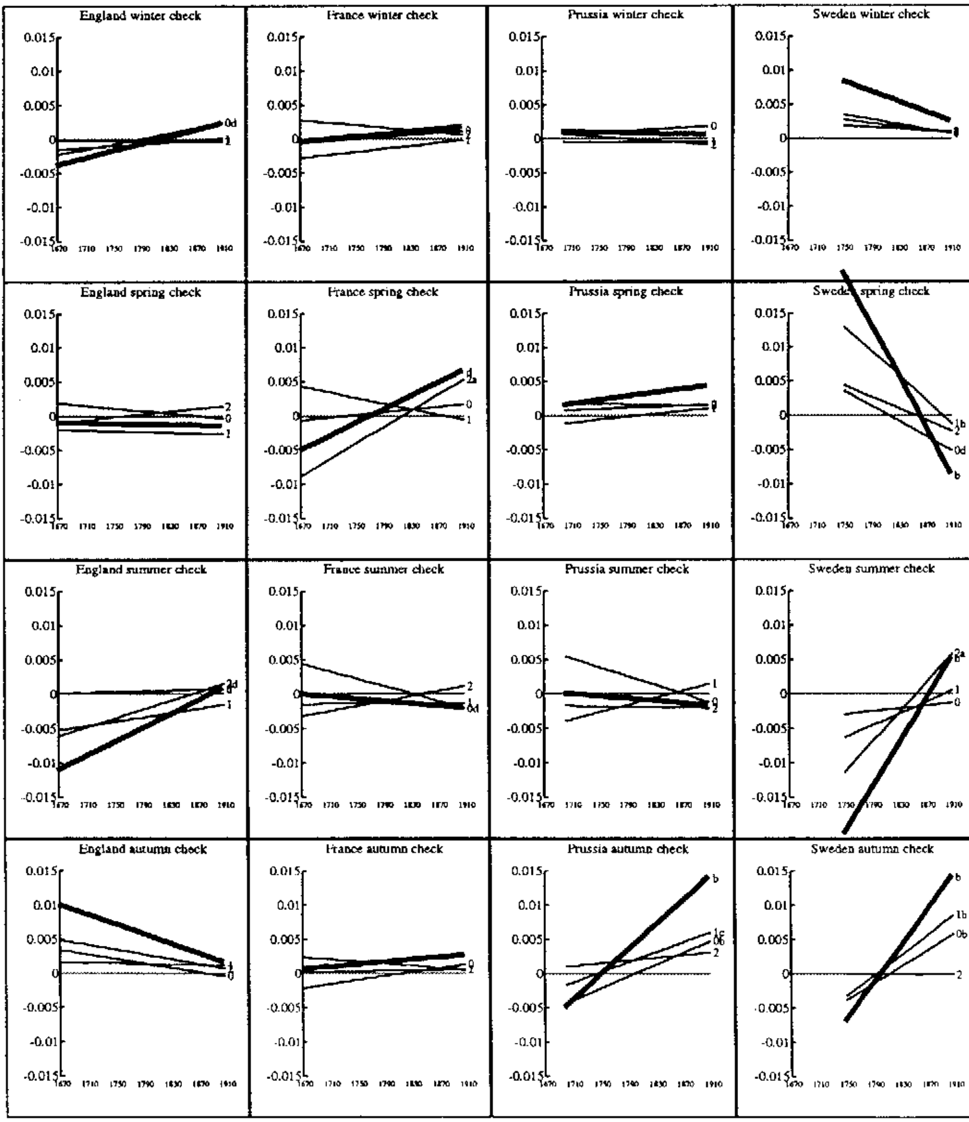


Fig. 7a. Changes in the short-term temperature-fertility checks over time in England, France, Prussia and Sweden. The response of fertility to an increase in winter, spring, summer, and autumn temperature independent of price and non-infant mortality effects is shown. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. The number to the right of the line is the lag. The thick black line is the lag sum. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation DD.

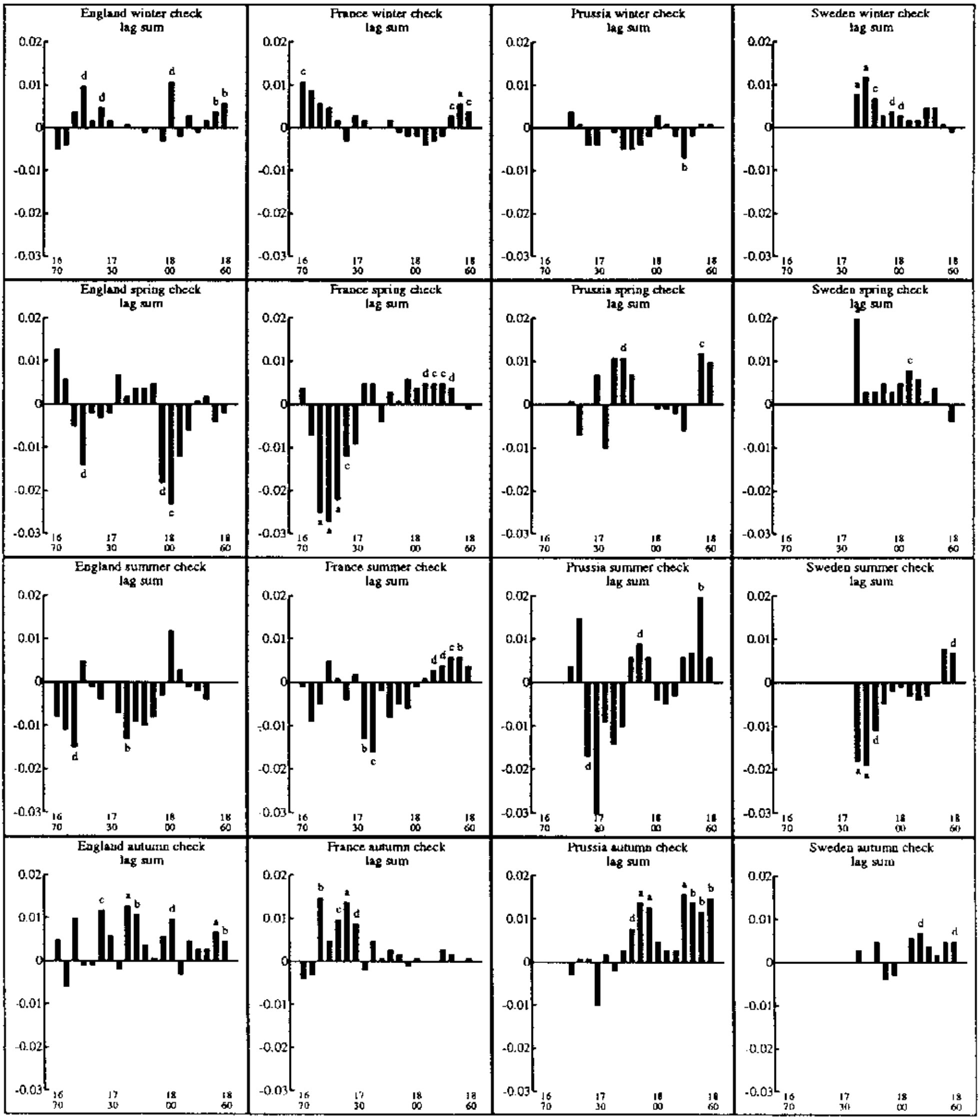


Fig. 7b. Changes in the short-term temperature-fertility checks over time in England, France, Prussia and Sweden. The lag sum response of fertility to an increase in winter, spring, summer, and autumn temperature independent of price and non-infant mortality effects is shown. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. The columns are the response during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation D.

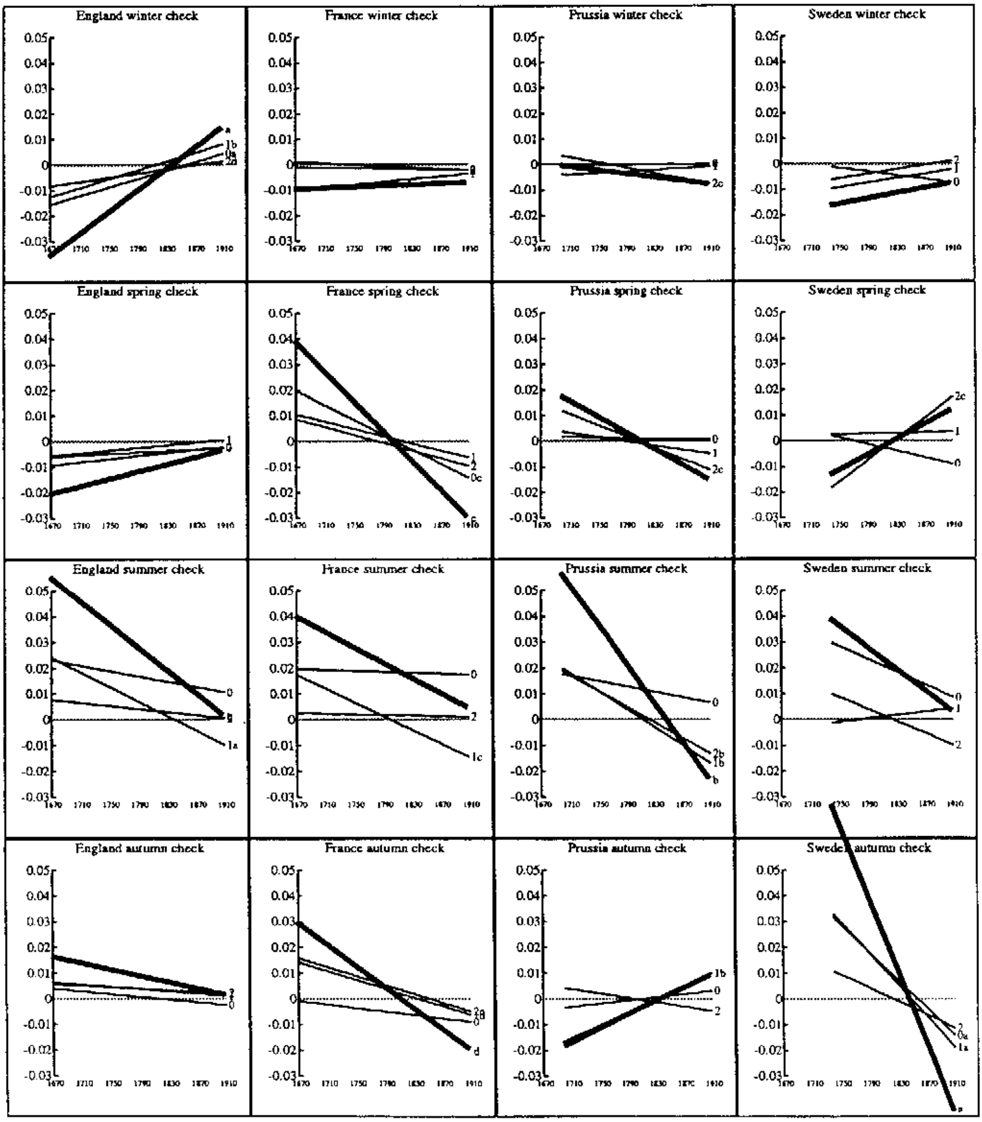


Fig. 8a. Changes in the short-term temperature-mortality checks over time in England, France, Prussia and Sweden. The response of mortality to an increase in winter, spring, summer, and autumn temperature independent of price effects is shown. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. The number to the right of the line is the lag. The thick black line is the lag sum. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation GG.

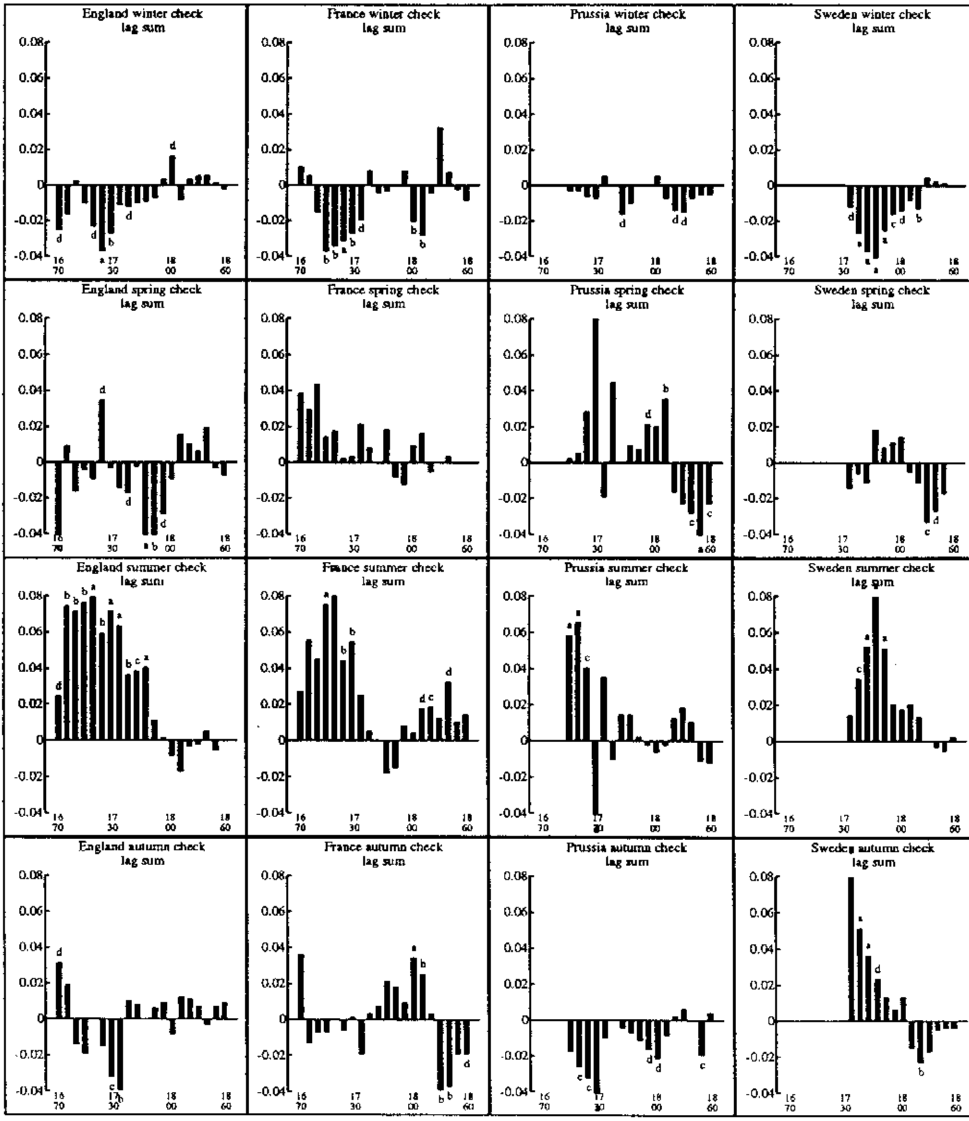


Fig. 8b. Changes in the short-term temperature-mortality checks over time in England, France, Prussia and Sweden. The lag sum response of mortality to an increase in winter, spring, summer, and autumn temperature independent of price effects is shown. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation G.

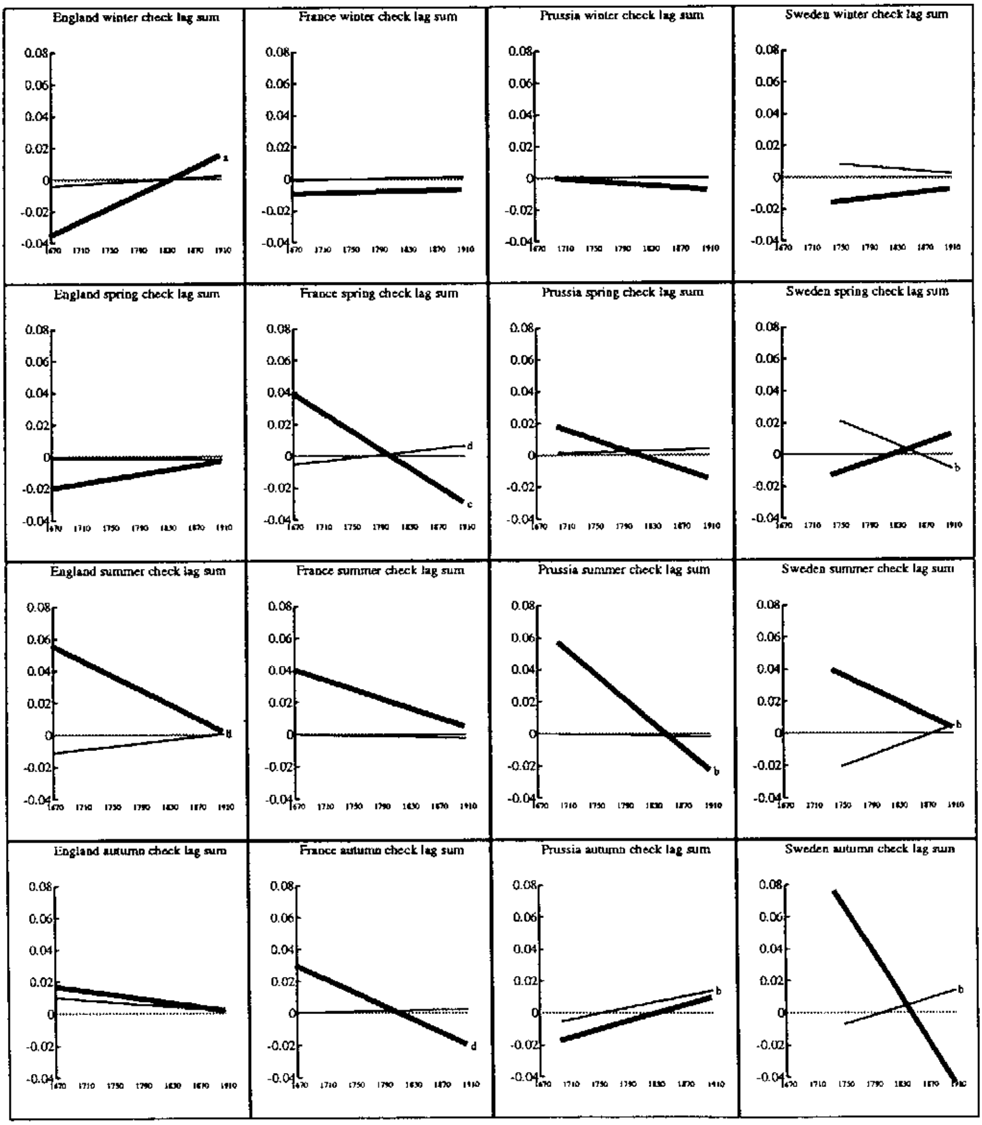


Fig. 9a. Changes in the short-term temperature checks over time in England, France, Prussia and Sweden. The thin black line is the lag sum response of fertility to an increase in temperature independent of price and non-infant mortality effects. The thick black line is the lag sum response of mortality to an increase in temperature independent of price effects. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. Significance of the slope is indicated as follows: a 1%, b 5%, c 10%, d 20%. Sources: Equations DD and GG.

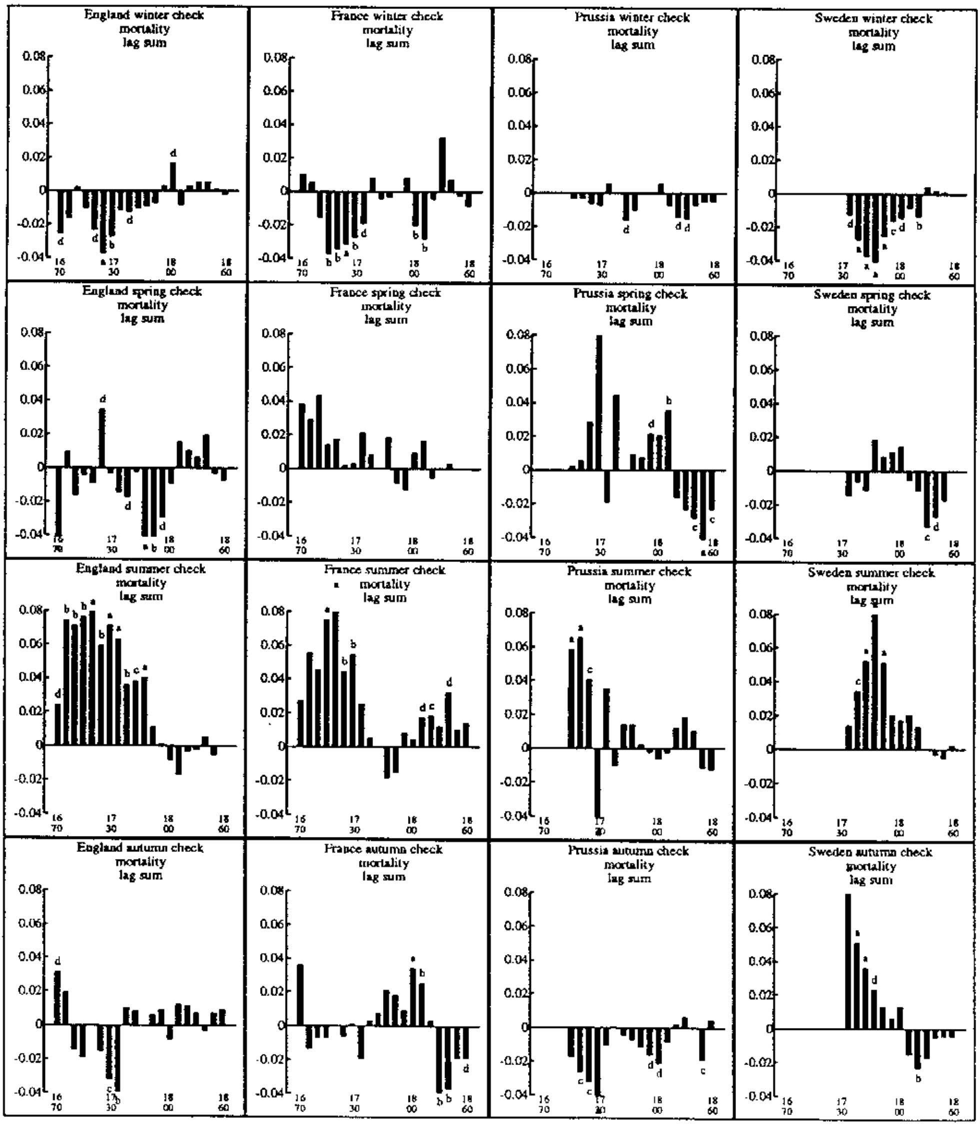


Fig. 9b. Changes in the short-term temperature-mortality checks over time in England, France, Prussia and Sweden. The lag sum response of mortality to an increase in winter, spring, summer, and autumn temperature independent of price effects is shown. The vertical axis represents the magnitude of the response in terms of a one degree Fahrenheit increase in temperature. The columns are the responses during a fifty year interval. The horizontal axis shows the beginning year of the fifty year interval. Significance is indicated as follows: a 1%, b 5%, c 10%, d 20%. Source: Equation G.

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