Population Studies, **42** (1988), 275–303
Printed in Great Britain

Basic Patterns in Annual Variations in Fertility, Nuptiality, Mortality, and Prices in Pre-industrial Europe*

PATRICK R. GALLOWAY†

> For him [Keynes] the short run was much more significant than the long run – that long run, in which, as he used to say, 'we are all dead'...[1]

While there has been great interest among scholars in long-term demographic phenomena, the historical actor was primarily concerned with short-term events. Given an average life expectancy of 25–35 years, the typical European peasant was probably unaware of long-term swings in climate, real wages, and prices. His experiences revolved around the passing of the seasons. The important events in his life were harvest, childbirth, marriage, death, religious festivals, taxes for most, and an occasional war or epidemic for all.

The present study focuses on the relationship between annual variations in grain prices and annual fluctuations in fertility, nuptiality, mortality, and population growth in a number of pre-industrial European countries. The direction, magnitude, and temporal structure of the responses of vital rates to fluctuations in grain prices are estimated, and differences and similarities of response are discussed. The analysis allows inferences to be made about the relative strength of the short-term Malthusian preventive and positive checks and about the role development, income, and urbanization levels play in the determination of the timing and magnitude of these checks.

The analysis of short-term (annual) fluctuations circumvents many problems inherent in long-term analysis. For example, long-term variations in population size itself can affect agricultural production by stimulating technological innovation which can lead to changes in the standard of living, that may affect vital rates, which by definition govern population size.[2] Short-term analysis of vital rates provides the demographer with an important technical advantage over long-term analysis. Most of the variation from one year to the next takes place in the numerator, i.e. the births, marriages or deaths themselves, while variations in the denominator, i.e. population size, tend to be relatively

* The research on which this article is based has been funded by grants R01-HD18107 and T32-HD07275 from the U.S. National Institute of Child Health and Human Development. I thank Ronald D. Lee, Eugene A. Hammel, Roger S. Schofield, David R. Weir, Vicente Pérez-Moreda, Andrew Foster, and Jack M. Potter for helpful comments and suggestions.

† Graduate Group in Demography, Program in Population Research, University of California, 2232 Piedmont Avenue, Berkeley, California 94720, U.S.A.

[1] A. C. Pigou, 'John Maynard Keynes, economist', *Proceedings of the British Academy*, **32** (1946), p. 407.

[2] E. Boserup, *Population and Technological Change, A Study of Long-Term Trends* (Chicago: University of Chicago Press, 1981). R. D. Lee, 'Population homeostasis and English demographic history', *Journal of Interdisciplinary History*, **15**, 4 (1985), pp. 635–660. P. R. Galloway, 'Long-term fluctuations in climate and population in the preindustrial era', *Population and Development Review*, **12**, 1 (1986), pp. 1–24. R. D. Lee, 'Malthus and Boserup: a dynamic synthesis', in *The State of Population Theory, Forward from Malthus*, ed. D. Coleman and R. Schofield (Oxford: Blackwell, 1986), pp. 96–130.

small, given, of course, a sufficiently large population.[3] In other words, from one year to the next, population size is virtually constant relative to changes in vital events. As a consequence, annual variations in, say, births represent an effective substitute for annual variations in the crude birth rate. This is important for the historical investigator since population counts are relatively scarce and less reliable than the more plentiful series of births, marriages, and deaths compiled by pre-industrial European clerics and officials. Furthermore, annual variations in the harvest are primarily determined by complicated meteorological events. It can confidently be assumed that in pre-industrial Europe annual changes in the harvest and variations in the weather were exogenous relative to annual fluctuations in vital events. These straightforward assumptions enhance the validity of the specified models and allow clear inferences to be made about the direction of causality.

GRAIN PRICES, THE HARVEST, AND THE PRE-INDUSTRIAL ECONOMY

Annual variations in grain prices are used as a proxy for annual variations in the standard of living.[4] From one year to the next, fluctuations in the price of grain were the primary determinants of variations in the real wage. It can be observed empirically that nominal wages rarely fluctuated from year to year, while consumer prices, which were dominated by grain, tended to vary substantially. Adam Smith found that 'The wages of labour do not in Great Britain fluctuate with the price of provisions. These vary everywhere from year to year, frequently from month to month. But in many places the money price of labour remains uniformly the same sometimes for half a century... The high price of provisions during these ten years past has not in many parts of the kingdom been accompanied with any sensible rise in the money price of labour'.[5]

In an economy where grain is stored, imported, or where its distribution is controlled for one reason or another, annual variations in grain prices generally will be a more accurate indicator of annual fluctuations in the quantity of grain available for consumption than annual variations in the harvest.[6] For example, an increase in grain stored as a result of a bumper crop in one year would tend to buffer the negative effects of a poor harvest the following year. This may be reflected in a relatively moderate price change compared to the change in output. Suppose a region suffers a catastrophic crop failure as a result of adverse weather conditions, but the harvest is abundant elsewhere.

[3] B. Spencer, 'Size of population and variability of demographic data, 17th and 18th centuries', *Genus*, **32**, 3–4 (1976), pp. 11–42. R. D. Lee, 'Methods and models for analyzing historical series of births, deaths, and marriages', in *Population Patterns in the Past*, ed. R. D. Lee (New York: Academic Press, 1977), pp. 337–370.

[4] R. D. Lee, 'Short-term variation: vital rates, prices and weather', in *The Population History of England 1541–1871, A Reconstruction*, E. A. Wrigley and R. S. Schofield (Cambridge: Harvard University Press, 1981), pp. 356–401; G. Fridlizius and R. Ohlsson, 'Mortality patterns in Sweden 1751–1802, a regional analysis', in *Pre-Industrial Population Change*, ed. T. Bengtsson, G. Fridlizius, and R. Ohlsson (Stockholm: Almqvist and Wiksell, 1984), pp. 299–328; T. Richards, 'Weather, nutrition and the economy: the analysis of short-run fluctuations in births, deaths and marriages, France 1740–1909', in Bengtsson *et al.*, *ibid.*, pp. 357–389; D. R. Weir, 'Life under pressure: France and England, 1670–1870', *Journal of Economic History*, **44**, 1 (1984), pp. 27–47; P. R. Galloway, 'Annual variations in deaths by age, deaths by cause, prices, and weather in London 1670 to 1830', *Population Studies*, **39**, 3 (1985), pp. 487–505; T. Bengtsson, 'Comparisons of population cycles and trends in England, France and Sweden 1751–1860'. Paper presented at the Ninth International Economic History Congress, Bern, 1986; P. R. Galloway, 'Differentials in demographic responses to annual price variations in pre-revolutionary France: a comparison of rich and poor areas in Rouen, 1681 to 1787', *European Journal of Population*, **2**, 3/4 (1986), pp. 269–305; and P. R. Galloway, Population, Prices, and Weather in Preindustrial Europe, Ph.D. disssertation, Graduate Group in Demography, University of California, Berkeley, 1987.

[5] A. Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), revised, corrected, and improved by J. R. M'Culloch (Edinburgh: Adam and Charles Black, 1863), book 1, chapter 8.

[6] Fridlizius and Ohlsson, *op. cit.* in footnote 4, p. 305.

Increased interregional trade could augment the deficient supply of grain. The amount of grain consumed, and the grain price, would depend more on the grain supply among the regions involved in trade than the actual harvest within a particular region.

In general, annual variations in the harvest as reflected in annual fluctuations in the price of grain affected nearly every sector of the European economy. Bowden suggested that '...high prices were the outcome of poor harvests and food scarcities; at such times many small cultivators were likely to be forced into the market-place as buyers of grain (at famine prices) rather than as sellers of surplus produce... While the good harvests which served to depress the price of corn were inimical to the financial interests of the larger cereal producers, they obviously benefited the general body of bread-eating and liquor-drinking consumers, and provided livestock farmers with a degree of compensation for deficient crops of hay. In addition to permitting an increase in the consumption of other domestically produced agricultural commodities, the purchasing power released by low grain prices also resulted in a more buoyant demand for manufactured goods and imported foodstuffs.... Conversely with bad harvests'.[7]

Labrousse outlined the consequences of a poor harvest: '1. A harvest failure drove prices up. 2. For the majority of farmers a bad harvest meant a loss of income inasmuch as the higher price per unit did not make up for the drop in marketable produce. To that loss must be added the loss to the labourers of employment and income, because less corn had to be gathered and processed. 3. Owing to the bad harvest the townspeople were forced to spend more on provisions. To buy essential foodstuffs they had to do without other commodities. Demand for the services and products of industry fell off. 4. Owing to this, and because the peasants could not buy so much, markets and trade stagnated. There was less demand for labourers; wages were low or sank still lower; men sought work and could not find it'.[8]

Jones noted that, 'the size of the grain harvest, besides having the most obvious and most crucial bearing on the spare purchasing power of the ordinary consumer, influenced the quantity and price of the raw materials of other industries, such as brewing, distilling and starchmaking'.[9]

Abel[10] found that large farms, i.e. large in terms of marketable production, increased profits as a result of a bad harvest, while profits of middle-size farms were hardly affected. Small farmers, the majority of pre-industrial European farmers, suffered major losses as a result of a poor harvest.

Fogel[11] estimated differential mortality responses to changes in the harvest by class in England. He suggested that mortality increase as a result of a harvest failure would be confined largely, if not exclusively, to the poor.

In general, a poor harvest generated high cereal prices which benefited the large grain producers and distributors, who were relatively few in number. Most of the population of pre-industrial Europe, the landless labourers, the small farmers, and most urban dwellers, suffered. It is essentially their demographic responses to variations in grain prices that will dominate any analysis at the national level. Using less aggregated units of analysis where the responses of the rich may be distinguished from those of the poor,

[7] P. J. Bowden, 'Agricultural prices, wages, farm profits, and rents', in *The Agrarian History of England and Wales*, vol. V, *1640–1750, II. Agrarian Change*, ed. J. Thirsk (Cambridge: Cambridge University Press, 1985), pp. 61 and 93.

[8] W. Abel, *Agricultural Fluctuations in Europe from the Thirteenth to the Twentieth Centuries* (London: Methuen, 1980), p. 9.

[9] E. L. Jones, *Seasons and Prices, the Role of the Weather in English Agricultural History* (London: George Allen & Unwin, 1964), p. 22.

[10] Abel, *op. cit.* in footnote 8, pp. 9–13.

[11] R. W. Fogel, 'Nutrition and the decline in mortality since 1700: some additional preliminary findings', National Bureau of Economic Research Working Paper No. 1802 (1986), p. 85.

differences along the lines suggested or implied by Bowden, Labrousse, Abel, and Fogel have been found.[12]

There exists an extensive literature concerning the impact of annual harvest variations, usually measured by grain prices, on vital rates in pre-industrial Europe.[13] Most of these

[12] An analysis of Rouen urban parishes can be found in Galloway, *loc. cit.* in footnote 4, (1986). For a study of small districts in rural Arhus Diocese, Denmark, see Galloway, *op. cit.* in footnote 4 (1987), pp. 193–218.

[13] For analyses of England see for example W. Farr, 'The influence of scarcities and of the high prices of wheat on the mortality of the people of England', *Journal of the Royal Statistical Society*, **9** (1846), pp. 158–174; G. U. Yule, 'On the changes in the marriage and birth rates in England and Wales during the past half century; with an inquiry as to their probable causes', *Journal of the Royal Statistical Society*, **69** (1906), pp. 88–132; J. K. Edwards, 'Norwich Bills of Mortality 1707–1830', *Yorkshire Bulletin of Economic and Social Research*, **21**, 2 (1969), pp. 94–113; E. A. Wrigley, *Population and History*, (New York: McGraw-Hill, 1969); A. B. Appleby, 'Nutrition and disease: the case of London, 1550–1750', *Journal of Interdisciplinary History*, **6**, 1 (1975), pp. 1–22; P. Mirowski, 'The plague and the penny-loaf: the disease-dearth nexus in Stuart and Hanoverian London', unpublished manuscript, Department of Economics, University of Michigan, 1976; J. Landers, 'Mortality, weather and prices in London 1675–1825: a study of short-term fluctuations'. *Journal of Historical Geography*, **12**, 4 (1986), pp. 347–364; A. B. Appleby, 'Grain prices and subsistence crises in England and France, 1590–1740', *Journal of Economic History*, **39**, 4 (1979), pp. 865–888; E. A. Wrigley and R. S. Schofield, *The Population History of England 1541–1871, A Reconstruction* (Cambridge: Harvard University Press, 1981); and R. Schofield, 'The impact of scarcity and plenty on population change in England, 1541–1871', in *Hunger and History, the Impact of Changing Food Production and Consumption Patterns on Society*, ed. R. I. Rotberg and T. K. Rabb (Cambridge: Cambridge University Press, 1985), pp. 67–93.

For studies of France see for example J. Meuvret, 'Les crises de subsistances et la démographie de la France d'ancien régime', *Population*, **1**, 4 (1946), pp. 643–650; P. Goubert, 'En Beauvaisis: problèmes démographiques du XVII^e siècle', *Annales Economies Sociétés Civilisations*, **7**, 4 (1952), pp. 453–468; P. Goubert, *Beauvais et le Beauvaisis de 1600 à 1730* (Paris: SEVPEN, 1960); J. Meuvret, 'Demographic crisis in France from the sixteenth to the eighteenth century', in *Population in History, Essays in Historical Demography*, ed. D. V. Glass and D. E. C. Eversley (London: Arnold, 1965), pp. 507–522; A. Lefebvre-Teillard, *La Population de Dole au XVIII^e Siècle* (Paris: Presses Universitaires de France, 1969); F. Lebrun, *Les Hommes et la Mort en Anjou aux 17^e et 18^e Siècles* (Paris: Mouton, 1971); P. Goubert, *The Ancien Régime, French Society, 1600–1700* (New York: Harper and Row, 1973); J. C. Perrot, *Genèse d'une Ville Moderne: Caen au XVIII^e Siècle* (Paris: Mouton, 1975); R. Beaudry, 'Alimentation et population rurale en Périgord au XVIII^e siècle', *Annales de Démographie Historique*, (1976), pp. 41–59; F. Lebrun, 'Les crises démographiques en France aux XVII^eet XVIII^e siècles', *Annales Economies Sociétés Civilisations*, **35**, 2 (1980), pp. 205–234; and J.-P. Bardet, *Rouen aux XVII^e et XVIII^e Siècles, les Mutations d'un Espace Social* (Paris: CDU et SEDES, 1983).

For analyses of Germany see A. Schreiber, 'Die Entwicklung der Augsburger Bevölkerung vom Ende des 14 Jahrhunderts bis zum Beginn des 19 Jahrhunderts', *Archiv für Hygiene und Bakteriologie*, **123** (1940), pp. 90–177; F. G. Dreyfus, 'Prix et population à Trèves et à Mayence au XVIII^e siècle', *Revue d'Histoire Économique et Sociale*, **34**, 3 (1956), pp. 241–261; E. François, 'La population de Coblence au XVIII^e siècle', *Annales de Démographie Historique* (1975), pp. 291–341; G. Hohorst, *Wirtschaftswachstum und Bevölkerungsentwicklung kin Preussen 1816 bis 1914* (New York: Arno, 1977); M. W. Paas, *Population Change, Labor Supply, and Agriculture in Augsburg 1480–1618* (New York: Arno, 1981).

Scandinavian studies include E. F. Heckscher, *Sveriges Ekonomiska Historia från Gustav Vasa* (Stockholm: Bonniers, 1935); D. S. Thomas, *Social and Economic Aspects of Swedish Population Movements, 1750–1933* (New York: Macmillan, 1941); H. Gille, 'The demographic history of the northern European countries in the eighteenth century', *Population Studies*, **3**, 1 (1949), pp. 3–65; E. F. Heckscher, *An Economic History of Sweden* (Cambridge: Harvard University Press, 1954); G. Utterström, 'Some population problems in pre-industrial Sweden', *Scandinavian Economic History Review*, **2**, 2 (1954), pp. 103–165; E. Jutikkala, 'The great Finnish famine in 1696–97', *Scandinavian Economic History Review*, **3**, 1 (1955), pp. 48–63; G. Utterström, 'Climatic fluctuations and population problems in early modern history', *Scandinavian Economic History Review*, **3**, 1 (1955), pp. 3–47; G. Utterström, 'Two essays on population in eighteenth-century Scandinavia' in Glass and Eversley (eds.) *loc. cit.* above, pp. 523–548; A. E. Imhof, *Aspekte der Bevölkerungsentwicklung in den nordischen Ländern 1720–1750* (Bern: Francke, 1976); O. Turpeinen, 'Infant mortality in Finland 1749–1865', *Scandinavian Economic History Review*, **27**, 1 (1979), pp. 1–21; O. Turpeinen, 'Les causes des fluctuations annuelles du taux de mortalité finlandais entre 1750 et 1806', *Annales de Démographie Historique*, (1980), pp. 287–296; Y. Kaukiainen, 'Harvest fluctuations and mortality in agrarian Finland (1810–1870)' in Bengtsson *et al.*, *op. cit.* in footnote 4, pp. 235–254; G. Fridlizius, 'The mortality decline in the first phase of the demographic transition: Swedish experiences', in Bengtsson *et al.*, *op. cit.* in footnote 4, pp. 71–114; and H. C. Johansen, 'Regional mortality fluctuations in Denmark 1735–1849'. Paper presented at the Ninth International Economic History Congress, Bern, 1986.

Studies covering other places include F. F. Mendels, 'Proto-industrialization: the first phase of the industrialization process', *Journal of Economic History*, **32** (1972), pp. 241–261; A. M. Piuz, 'Climat, récoltes investigations attempted to show some relationship between harvest or grain price variations and mortality levels. Fertility and nuptiality responses were occasionally discussed. From his classic analysis of the Beauvaisis, Goubert concluded 'The price of grain is almost everywhere a demographic barometer. The size and frequency of cyclical turning points in the price of grain determine the size and frequency of demographic crises. And these, in turn, largely determine movements in population and even the size of populations'.[14] There was general agreement with Goubert that variations in grain prices did affect vital rates, but more precise estimates of the magnitude, timing, and significance of these effects awaited researchers who used more rigorous statistical techniques.[15] While these investigators invariably employed models which incorporated lagged effects, the methods and variables used were different enough to render direct comparisons difficult. Where comparative analysis was undertaken, no more than three countries were examined, and in no study were quantitative measures of living standards considered.

The present analysis investigates the responses of vital rates to fluctuations in grain prices in nine pre-industrial European countries, using a consistent statistical method. The results are interpreted and compared, based on measures of economic development, income level, and urbanization among the nine countries.

DATA AND PERIODS

Periodization of history is always somewhat arbitrary. However, there are two major structural phenomena which probably had a significant impact on short-term demographic fluctuations over the last millennium. Outbreaks of bubonic plague tended

et vie des hommes à Genève, XVI[e]–XVIII[e] siècle', *Annales Economies Sociétés Civilisations*, **29**, 3 (1974), pp. 599–618; C. Bruneel, *La Mortalité dans les Campagnes: le Duché de Brabant aux XVII[e] et XVIII[e] Siècles* (Louvain: Editions Nauwelaerts 1977); L. Del Panta and M. Livi-Bacci, 'Chronologie, intensité et diffusion des crises de mortalité en Italie: 1600–1850', *Population*, **32**, numéro spécial (1977), pp. 401–445; M. W. Flinn, ed., *Scottish Population History from the 17th Century to the 1930s* (Cambridge: Cambridge University Press, 1977); C. Pfister, 'Climate and economy in eighteenth-century Switzerland'), *Journal of Interdisciplinary History*, **9**, 2 (1978), pp. 223–243; A. Perrenoud, *La Population de Genève du Seizième au début du Dix-Neuvième Siècle, Etude Démographique* (Geneva, 1979); V. Pérez Moreda, *La Crisis de Mortalidad en la España Interior (Siglos XVI–XIX)* (Madrid: Siglo Veintiuno Editores, 1980); M. W. Flinn, *The European Demographic System, 1500–1820* (Baltimore: Johns Hopkins University Press, 1981); J. D. Post, *Food Shortage, Climatic Variability, and Epidemic Disease in Preindustrial Europe, the Mortality Peak in the Early 1740s* (Ithaca: Cornell University Press, 1985); and M. K. Matossian, 'Climate, crops, and natural increase in rural Russia, 1861–1913', *Slavic Review*, **45**, 3 (1986), pp. 457–469.

[14] Goubert, *loc. cit.* in footnote 13 (1952), p. 468.

[15] Lee, *op. cit.* in footnote 4; T. Bengtsson, 'Harvest fluctuations and demographic response: southern Sweden 1751–1859', in Bengtsson *et al.*, *op. cit.* in footnote 4, pp. 329–355; R. Ohlsson and T. Bengtsson, 'Population and economic fluctuations in Sweden 1749–1914', in Bengtsson *et al.*, *op. cit.* in footnote 4, pp. 277–297; Fridlizius and Ohlsson, *op. cit.* in footnote 4; Richards, *op. cit.* in footnote 4; Weir, *loc. cit.* in footnote 4; T. Bengtsson and R. Ohlsson, 'Age-specific mortality and short-term changes in the standard of living; Sweden, 1751–1859', *European Journal of Population*, **1**, 4 (1985), pp. 309–326; Galloway, *loc. cit.* in footnote 4 (1985); P. R. Galloway and R. D. Lee, 'Some possibilities for the analysis of aggregate historical demographic data from China'. Workshop in Qing Population History, California Institute of Technology, Pasadena, 1985; Z. Eckstein, T. P. Schultz, and K. I. Wolpin, 'Short-run fluctuations in fertility and mortality in pre-industrial Sweden', *European Economic Review*, **26** (1985), pp. 295–317; E. A. Hammel, 'Short-term demographic fluctuations in the Croatian military border of Austria, 1830–1847', *European Journal of Population*, **1**, 2/3 (1985), pp. 265–290; Bengtsson, *loc. cit.* in footnote 4 (1986); T. Bengtsson, 'Migration, wages and urbanization in Sweden in the nineteenth century', Department of Economic History, Lund University, 1986; T. Bengtsson and G. Broström, 'A comparison of different methods of analyzing cycles in population and economy'. Paper presented at the Ninth International Economic History Congress, Bern, 1986; Galloway, *loc. cit.* in footnote 4 (1986); T. P. Schultz, 'Short-term changes in economic and demographic variables: comparisons of preindustrial English and Swedish time series using alternative statistical frameworks'. Paper presented at the Ninth International Economic History Congress, Bern, 1986; and Galloway, *op. cit.* in footnote 4 (1987).

to dominate short-term variations in demographic events from its appearance in 1348 to its mysterious disappearance from most of Europe after 1670. The last half of the nineteenth century witnessed the rapid industrialization of most European countries accompanied by the onset of the so-called demographic transition, a period when fertility and mortality rates underwent long-term declines of unprecedented magnitude. As a consequence five historical demographic eras can be identified: pre-plague (before 1348), plague (1348 to the 1670s), post-plague and pre-demographic transition (1675 to about 1870), demographic transition (from around 1870 to the first half of the twentieth century), and post-World War II.

No vital registration data exist at the national level for the pre-plague era. Indeed, England is the only country for which national data have been gathered covering the plague era. As is shown in Table 1, the era 1675–1870 is sub-divided into two periods: 1675–1755 and 1756–1870 since reliable series of vital rates for France, Denmark, Prussia and Sweden do not begin until around the middle of the eighteenth century. The onset of the periods used in the analysis for the Netherlands, Belgium, Tuscany, and Austria are determined by data availability. Because this analysis is concerned with the pre-industrial and pre-transition era all series are terminated at 1870, though it is realized that, in fact, some districts in Europe were already highly industrialized by 1870 and that the fertility transition may have actually begun in France as early as the eighteenth century.

In this study vital rates are available for all areas except rural France 1677–1734, Minden-Kleve 1695–1751, and central Prussia 1696–1755, where vital events are used. Finland and Norway are excluded from the analysis. There are excellent long series of vital rates for both these countries but no directly applicable price series of sufficient length. Excepting Tuscany, eastern and southern Europe are not represented because national level vital registration series of sufficient length are not available for the period under consideration. Details regarding the sources of the demographic data can be found in the Data Appendix.

As was explained earlier, annual variations in grain prices generally reflect annual fluctuations in the standard of living. In this analysis, rye prices are used for Sweden, Denmark, Prussia, Austria, Netherlands, and Belgium while wheat prices are used for England, France, and Tuscany. Within a large country, a number of geographically representative price series were combined to form an average national price series. The sources of the grain price series are listed in the Data Appendix.

The dates designating the temporal interval for the series shown in Table 1 are for the detrended series. The proposed method, which will be discussed later, places strong demands on the length of the series employed. The detrending procedure eliminates ten data points from the raw series, the lag structure eliminates another four, and the correction for second-order autoregressive disturbances eliminates two more. In general a minimum series length of about 50 years after detrending and after accounting for lag structure has been selected.

The temporal unit of analysis for the demographic and price variables is the calendar year (1 January to 31 December). Nearly all publications present series of annual vital statistics by calendar year. Most grain price series are available by calendar year, or are published monthly from which calendar year prices can be calculated. All data in this analysis are calendar year, with two exceptions. Harvest year vital rates and prices are used for England 1546–1674, because calendar year prices are not available for England for the entire period. Harvest year vital rates and prices are used for part of the Austria series because calendar year vital rates are not available for Austria until 1856. See the Data Appendix for details.

Table 1. *Means of the raw series and coefficients of variation of the detrended series*

Place	Period	Percentage of pop. in agri. in 1870	Income per head (1970 US$)	Percentage urban	CBR	CMR	NIDR	CDR
			Mean of the raw series					
England	1756–1870	22.7*	526†	30.2†	37.0	8.4	18.8	24.9
Netherlands	1811–1870	37.0	—	—	33.9	7.9	19.3	25.7
Belgium	1811–1870	43.0	—	—	32.5	7.2	19.0	24.3
France	1756–1870	49.2	411	11.8	32.8	8.2	21.8	29.1
Prussia	1756–1870	49.5‡	346‡	8.8‡	40.0	9.1	22.6	30.2
Denmark	1756–1870	51.7	394	10.7	31.0	8.3	18.5	24.3
Sweden	1756–1870	53.9	320	4.2	32.6	8.0	19.1	24.9
Tuscany	1817–1870	62.0§	—	—	38.0	7.7	20.1	28.7
Austria	1827–1870	65.0	—	—	38.2	8.3	22.3	31.9
England	1675–1755	—	—	—	32.4	8.2	23.0	29.3
France Rural	1677–1734	—	—	—	N.A.	N.A.	N.A.	N.A.
Minden–Kleve	1695–1751	—	—	—	N.A.	N.A.	N.A.	N.A.
Central Prussia	1696–1755	—	—	—	N.A.	N.A.	N.A.	N.A.
England	1546–1674	—	—	—	32.4	9.0	20.7	26.4

Place	Period	CBR	CMR	NIDR	CDR	Grain prices
		Coefficient of variation of the detrended series				
England	1756–1870	0.028	0.056	0.064	0.049	0.199
Netherlands	1811–1870	0.044	0.089	0.115	0.089	0.236
Belgium	1811–1870	0.040	0.079	0.093	0.078	0.244
France	1756–1870	0.026	0.102	0.111	0.084	0.179
Prussia	1756–1870	0.044	0.088	0.132	0.101	0.229
Denmark	1756–1870	0.036	0.073	0.133	0.101	0.238
Sweden	1756–1870	0.052	0.076	0.165	0.134	0.172
Tuscany	1817–1870	0.051	0.134	0.229	0.156	0.142
Austria	1827–1870	0.051	0.093	0.187	0.129	0.250
Average		0.041	0.088	0.137	0.102	0.210
England	1675–1755	0.045	0.074	0.132	0.101	0.223
France Rural	1677–1734	0.066	0.152	0.218	N.A.	0.253
Minden–Kleve	1695–1751	0.053	0.067	0.187	0.141	0.254
Central Prussia	1696–1755	0.049	0.067	0.140	0.100	0.246
Average		0.053	0.090	0.169	0.114	0.244
England	1546–1674	0.066	0.123	0.202	0.153	0.241

Notes: NIDR = (total deaths − deaths under age one) × 1000/population. The Denmark CMR series is 1782 to 1870. The detrended series for France Rural, Minden–Kleve, and Central Prussia are for births, marriages, non-infant deaths, and total deaths. A series is detrended by dividing each data point, x, in the series by an eleven-year average of data points centered around x.

Sources: See Data Appendix.

* United Kingdom. † England and Wales. ‡ Germany. § Italy.

In countries where grain storage, grain import, and substitution with other types of food products play important roles, the effect of a poor harvest and higher grain prices on vital rates will probably be weaker than in countries functioning closer to the subsistence level. The impact of a poor harvest on vital rates should diminish as market integration increases, the transport network expands, sufficient capital is accumulated to import grain during poor harvest years, distribution becomes more efficient, and superior agricultural technology is used which is reflected in relatively higher yields, storage capacity, and diversity of crops grown.

It is difficult to find very reliable measures of economic development for different countries in pre-industrial Europe. In Table 1 we show the three measures used in this analysis. The percentage of the working population employed in the agricultural sector is available for all countries for the year 1870. This figure is not optimal, since the responses of vital rates to changes in grain prices will be estimated in various countries over time. There is a more serious problem for comparative analysis as a result of differences in the onset of the period under investigation from country to country. For example, in the Netherlands, Belgium, Tuscany, and Austria mortality series begin after the introduction of smallpox vaccination, while the series for England, France, Denmark, Prussia, and Sweden include the last half of the eighteenth century when vaccination was unknown. Similar arguments revolve around the increased cultivation of the potato and the marked increase in crop yields during the nineteenth century.

The magnitude of this problem can be reduced by restricting the analysis to countries over a relatively long and common time period. There are five countries for which responses can be estimated for the period 1756–1870: England, France, Prussia, Denmark, and Sweden. Average income per head and the average percentage of the urban population during the period 1756–1870 are shown in Table 1. While the figures are admittedly rough, they probably convey at least the correct ranking among the countries. Greater confidence may be justified as a result of the striking correspondence between the figures of income per head and percentages urban considering the wide variety of sources and methods used in their determination (see the Data Appendix).

METHOD

In order to assess the impact of annual variations of one variable on another over time it is essential to remove the long-term trend. This is accomplished by dividing each point in a series, x, by an eleven-year average of points centered around x. The mean of the resulting detrended series is nearly unity, hence its coefficient of variation is virtually the same as the standard deviation of the series. This method of detrending also removes the 15–20-year cycles caused by changes in population size or age structure.[16] All series used in the regressions in this study have been detrended by this method.

The basic idea is to estimate the magnitude and lag structure of the response of the dependent variable (crude birth rate, crude marriage rate, non-infant death rate, or crude death rate) to annual changes in the independent variable (prices). The rationale behind the selection of the dependent and independent variables will be discussed later. It is likely that the dependent variable is affected not only by the impact of the contemporary explanatory variable, but also by previous values of the explanatory variable. A distributed lag model is used to allow for effects of the independent variable on the dependent variable some years after the initial price shock.[17] The number of annual lags used in the estimation process is set at five years (lags 0, 1, 2, 3, and 4) for the independent demographic and price variables. Lengthening the lags beyond these

[16] Lee, *op. cit.* in footnote 4, p. 358.

[17] The method is similar to that used by Lee, *op. cit.* in footnote 4, pp. 356–359 and 739–740 and Galloway, *op. cit.* in footnote 4 (1987), pp. 13–16. Alternative statistical procedures such as two-stage least squares and instrumental variables used by Richards, *op. cit.* in footnote 4, p. 374; a vector autoregressive model used by Schultz, *loc. cit.* in footnote 15, pp. 19–20; and regressions of pooled data used by Galloway, *op. cit.* in footnote 4 (1987), pp. 251–269, provide little, if any, substantive improvement over the results obtained from the distributed lag model used in the present analysis. See Galloway, *op. cit.* in footnote 4 (1987), pp. 16–18 and 258, for a discussion of these and other statistical methods.

points generally provided no significant information, while decreasing degrees of freedom. Terminating the lags at these levels is consistent with previous research.[18]

Correction for second-order autoregressive disturbances is accomplished by using Cochrane and Orcutt's iterative procedure, where the error process is defined as $e_t = \rho_1 e_{t-1} + \rho_2 e_{t-2} + u_t$ where t is time, e is the error term, u is an independently distributed random variable, and ρ is a coefficient.[19] 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.[20] Because of the nature of the detrending procedure the estimated coefficients are elasticities.

R^2 and corrected R^2 are calculated for the untransformed variables. The significance of linear combinations of regression coefficients, usually the sum of the lags of each independent variable, is assessed. Non-linear effects of prices on vital rates are examined by including squared prices in the equations. To explore the possible impact of consecutive years of high prices on vital rates, a 'price runs' dummy variable has been constructed by assigning the value one to the second year of two consecutive years in which during each year prices were at least one standard deviation above the mean, the value two to the third year of three consecutive years in which during each year prices were at least one standard deviation above the mean, and so on. Possible non-linear effects of non-infant mortality on fertility and nuptiality responses are examined by including squared terms of non-infant mortality in the equations.[21]

The regression results are shown in Appendix Table 1 and will be discussed in the following sections. It should be noted that the calculations actually include data six years before the stated time period in order to account for lags 1, 2, 3, and 4 (four years) and the correction for second order autoregressive disturbances (two more years).

FERTILITY, PRICES, AND NON-INFANT MORTALITY

Fluctuations in fertility resulting from variations in grain prices may be caused by a number of factors which can be grouped theoretically according to biological or behavioural criteria, although it is often difficult to distinguish the two effects empirically. Biological responses resulting from increased malnutrition following high grain prices may include an increase in age at menarche, a reduction in the age of menopause, and increases in spontaneous abortion, anovulation and amenorrhoea.[22] An

[18] For the independent variables five years were used by Lee, *op. cit.* in footnote 4, p. 375; Richards, *op. cit.* in footnote 4, p. 365; Eckstein, Schultz, and Wolpin, *loc. cit.* in footnote 15, p. 306; Galloway, *loc. cit.* in footnote 4 (1985), pp. 495–496; Bengtsson and Ohlsson, *loc. cit.* in footnote 15, pp. 316–318; Galloway and Lee, *loc. cit.* in footnote 15, p. 10; Bengtsson, *loc. cit.* in footnote 4, p. 15 and 20; Galloway, *loc. cit.* in footnote 4 (1986), p. 282, and Schultz, *loc. cit.* in footnote 15, pp. 38–39. Bengtsson and Broström, *loc. cit.* in footnote 15, p. 9, used six years; Weir, *loc. cit.* in footnote 4, pp. 45–47, four; Hammel, *loc. cit.* in footnote 15, p. 281, three; Fridlizius and Ohlsson, *op. cit.* in footnote 4, p. 306, two; and Bengtsson, *loc. cit.* in footnote 15, p. 17, two.

[19] R. S. Pindyck and D. L. Rubinfeld, *Econometric Models and Economic Forecasts* (New York: McGraw-Hill, 1981), pp. 152–157.

[20] A. C. Harvey, *The Economic Analysis of Time Series* (Oxford: Philip Allan, 1981), pp. 189–199.

[21] Non-linear effects will be discussed briefly in this article. For a detailed analysis see Galloway, *op. cit.* in footnote 4 (1987), pp. 35–37 and 304–331.

[22] R. W. Hillman and R. S. Goodhart, 'Nutrition in pregnancy', in *Modern Nutrition in Health and Disease*, ed. R. S. Goodhart and M. E. Shils (Philadelphia: Lea and Febiger, 1973), pp. 647–658; E. Le Roy Ladurie, 'Famine amenorrhoea (seventeenth–twentieth centuries)', in *Biology of Man in History*, ed. R. Forster and O. Ranum (Baltimore: Johns Hopkins University Press, 1975), pp. 163–178; R. E. Frisch, 'Nutrition, fatness and fertility: the effect of food intake on reproductive ability', in *Nutrition and Human Reproduction*, ed. W. H. Mosley (New York: Plenum Press, 1978), pp. 91–122; R. E. Frisch, 'Population, food intake, and fertility', *Science*, **199** (1978), pp. 22–30; Z. Stein and M. Susser, 'Famine and fertility', in Mosley, *ibid.* pp. 123–145; J. Bongaarts, 'Does malnutrition affect fecundity? A summary of evidence', *Science*, **208** (1980), pp. 564–569; C. E. Gibbs and J. Seitchik, 'Nutrition in pregnancy', in *Modern Nutrition in Health and Disease*, ed.

increase in diseases often associated with malnutrition may also reduce fertility. As a consequence, it is usually difficult to determine whether reduced fertility is a result of mainly malnutritional effects or of some combination of malnutrition and infectious disease.[23] Fertility responses that might be categorized as behavioural would include induced abortion, voluntary control through increased conscious contraception, an increase in amenorrhoea as a result of psychological stress, an increase in abstinence, decreased libido, or a decrease in coital frequency caused by spousal separation as one or both partners search for means to obtain food, usually through employment, charity, or theft.

Direct evidence to measure the existence and importance of most of these factors is generally lacking for historical populations. In fact, there are practically no historical data that can come to terms with questions about annual variations in abortion, age at menarche, age at menopause or secondary sterility. Attempts to measure the extent of voluntary contraception are usually complicated by the difficulties involved in measuring the confounding influence of secondary sterility. Fluctuations in short-term migration resulting from fluctuations in grain prices and consequent inferred variations in coital frequency can be estimated by measuring short-term internal and external peasant migration. However, few data sets containing this type of information have yet been exploited along these lines.[24]

Previous historical research found that fertility was significantly negatively correlated with grain prices in England, France, and Sweden. A rise in fertility was associated with an increase in real wages in Sweden and in the harvest in Croatia. Outside Europe, Galloway and Lee found that high prices were strongly associated with a decline in fertility in pre-World War II Bombay Presidency, slightly associated with a fertility decrease in Taiwan, and not significantly related to fertility changes in Japan.[25]

Given the inability of existing data to consider many of the direct causal determinants of fertility change resulting from fluctuations in grain prices, one can still measure the magnitude and timing of the fertility response from country to country and speculate on the reasons behind the resulting consistency or inconsistency of response patterns. To that end regressions are run in which detrended crude birth rates are used as the dependent variable. Detrended grain prices and detrended non-infant death rates each distributively lagged five years are the independent variables. It is desirable to allow for the simultaneous impact of adult mortality fluctuations on fertility. Direct data on adult deaths are not available, so the non-infant death rate is used as a proxy for both adult mortality and morbidity. The non-infant death rate is calculated by subtracting infant

R. S. Goodhart, and M. E. Shils (Philadephia: Lea and Febiger, 1980), pp. 743–752; J. Menken, J. Trussell, and S. Watkins, 'The nutrition fertility link: an evaluation of the evidence', *Journal of Interdisciplinary History*, **11**, 3 (1981), pp. 425–441; B. A. Underwood, 'Marginal malnutrition and reproductive performance', in *Nutrition in Health and Disease and International Development: Symposia from the XIIth International Congress of Nutrition*, 1981, pp. 247–259; J. Bongaarts and R. G. Potter, *Fertility, Biology, and Behavior* (New York: Academic Press, 1983); R. Gray, 'The impact of health and nutrition on natural fertility', in *Determinants of Fertility in Developing Countries*, ed. R. A. Bulatao and R. D. Lee (New York: Academic Press, 1983), vol. 1, pp. 139–162.

[23] Gray, *op. cit.* in footnote 22, p. 140.

[24] Bengtsson, *loc. cit.* in footnote 15, p. 19, found that out-migration from manorial and peasant regions in Sweden increased significantly with rising rye prices.

[25] For England see Lee, *op. cit.* in footnote 4, p. 375; Weir, *loc. cit.* in footnote 4, pp. 46–47; Bengtsson, *loc. cit.* in footnote 4, p. 22; and Schultz, *loc. cit.* in footnote 15, p. 38. For France see Richards, *op. cit.* in footnote 4, p. 377; Weir, *loc. cit.* in footnote 4, pp. 45 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 22; and Galloway, *loc. cit.* in footnote 4 (1986), p. 286. For Sweden see Eckstein *et al.*, *loc. cit.* in footnote 15, p. 306; Bengtsson, *loc. cit.* in footnote 4, p. 22; and Schultz, *loc. cit.* in footnote 15, p. 38. For age-specific fertility responses to price changes in Sweden see Galloway, *op. cit.* in footnote 4 (1987), pp. 112–134. For Croatia see Hammel, *loc. cit.* in footnote 15, p. 286. For Bombay, Taiwan, and Japan see Galloway and Lee, *loc. cit.* in footnote 15, Table 1.

deaths from total deaths, multiplying this result by 1000, and then dividing by the population. Most of the annual variations in the fertility variable result from variations in marital fertility, since annual variations in births resulting from newly-weds or unmarried couples will have only a marginal impact on annual variations in overall fertility.[26]

The following regressions are run for each place shown in Table 1. Recall that all variables are detrended. B is the crude birth rate, P is prices, D^1 is the non-infant death rate, a is a constant, b and c are coefficients, e is an error term, and t is time:

$$B_t = a + \sum_{k=0}^{4} b_k P_{t-k} + e_t. \tag{1}$$

$$B_t = a + \sum_{k=0}^{4} b_k P_{t-k} + \sum_{k=0}^{4} c_k D^1_{t-k} + e_t. \tag{2}$$

The regression results may be interpreted as follows using France 1756 to 1870 as an example. (See Equation 1 in Appendix Table 1). Recall that the regression coefficients are elasticities. Say there is an increase of 100 per cent in prices at lag 0. This would result in a decrease in the crude birth rate of 4.0 per cent at lag 0, followed by a decrease of 7.9 per cent a year later, an increase of 5.2 per cent two years after the shock, a decrease of 1.6 per cent three years after, and an increase of 0.4 per cent four years after. The greatest effect occurs one year after the shock. This is what one might expect since the period of gestation is about nine months. The effect is negative and highly significant as predicted. As will be seen, the shape of this lag pattern is fairly typical. The lag sum, which is the net effect of a price shock cumulated over all five years, shows a decline of 7.9 per cent in the crude birth rate and is highly significant. Approximately 40 per cent of the variance in the crude birth rate is explained by variations in prices.

An examination of all countries in Appendix Table 1 shows that between 40 and 60 per cent of the variance in fertility can be explained by price fluctuations alone. Adding non-infant mortality to the regression (Equation 2) increases the range to between 50 and 70 per cent. These results suggest that pre-industrial European fertility variations were strongly associated with price fluctuations.

The χ^2-statistics show the joint significance of the independent variable sub-sets. The price and non-infant variables are typically highly significant. Additional regressions (not shown) reveal that squared terms and 'price runs' terms are generally not significant and do not increase the amount of variance explained.

The regression results also show the magnitude and pattern of the fertility responses across countries. In Figure 1, Panel A, the annual response patterns of fertility to price variations independent of non-infant mortality effects are plotted for each of the 14 places and periods. The data are from Equation 2 in Appendix Table 1. A thin line represents a country and the dotted line is the average of all the countries. Both the magnitudes of elasticities and the patterns of response are similar for all areas and all periods. The lag 0 response might reflect an increase in stillbirths, infanticide, or early expectations by some about next year's harvest leading to early modifications in fertility behaviour. However, the largest response generally occurs one year after the price shock, as expected. This could be attributed to a reduction in the number of conceptions resulting from increased famine or stress amenorrhoea, a greater frequency of induced and spontaneous abortions, more use of contraceptives or reduced coital frequency. The positive rebound at lag 2 can be attributed to fertility postponement.

[26] Lee, *op. cit.* in footnote 4, pp. 366–368 and Weir, *loc. cit.* in footnote 4, p. 39.

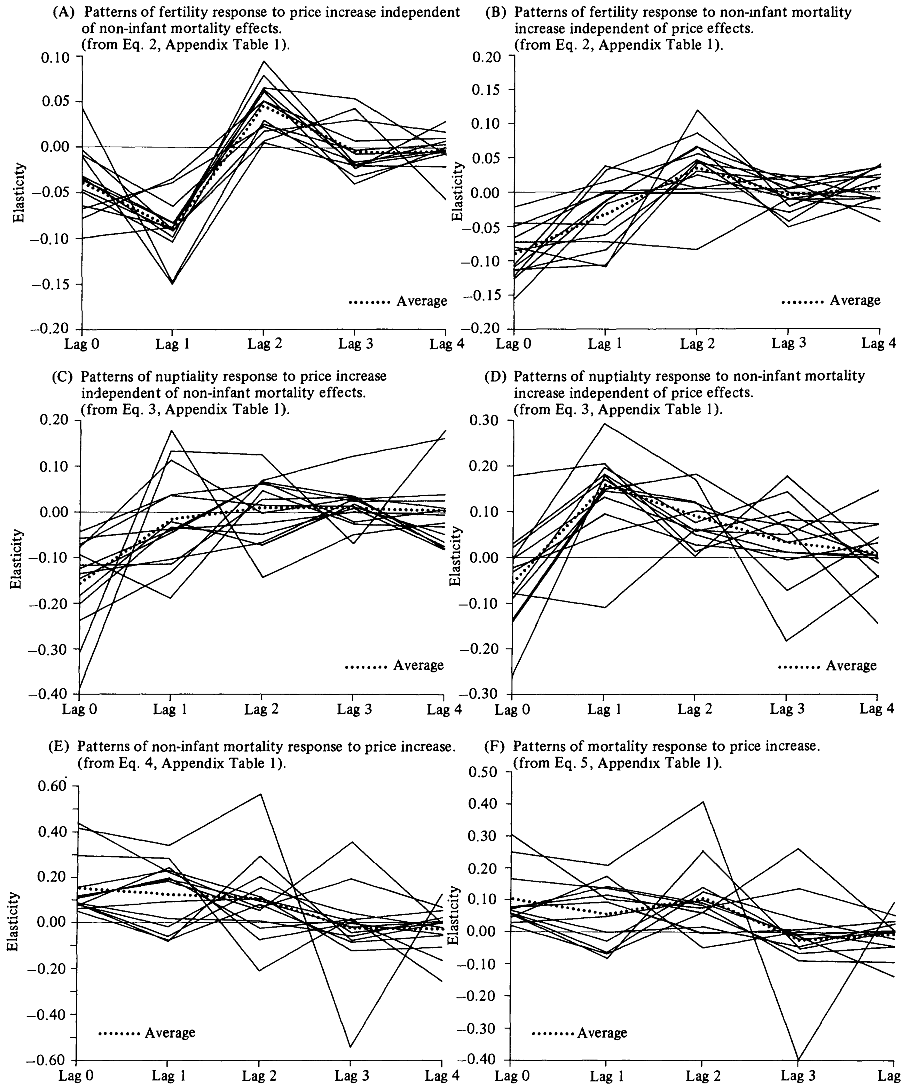

Figure 1. Patterns of fertility, nuptiality, and mortality responses to price increases in pre-industrial Europe. (Please note the use of different scales along the vertical axes.)

The great mass of regression results by country shown in Appendix Table 1 is partly summarized in Figure 2. In Figure 2 there are seven sets of bar graphs representing the cumulative responses over five years by country of vital rates to a price increase, and to an increase in non-infant mortality where relevant. Each bar graph is divided into three groups which display the responses by country according to measures of economic development. For example, the first group in the top row of bar graphs shows the cumulative fertility responses for England, France, Denmark, Prussia and Sweden in order by average income per head 1756–1870 and average percentage urban 1756–1870. The middle group shows cumulative fertility response for nine countries ranked by percentage of population engaged in agriculture in 1870. The last group shows the cumulative fertility response for six places and periods before 1756 in no particular order, since even rough estimates of comparative economic development are lacking for this early period.

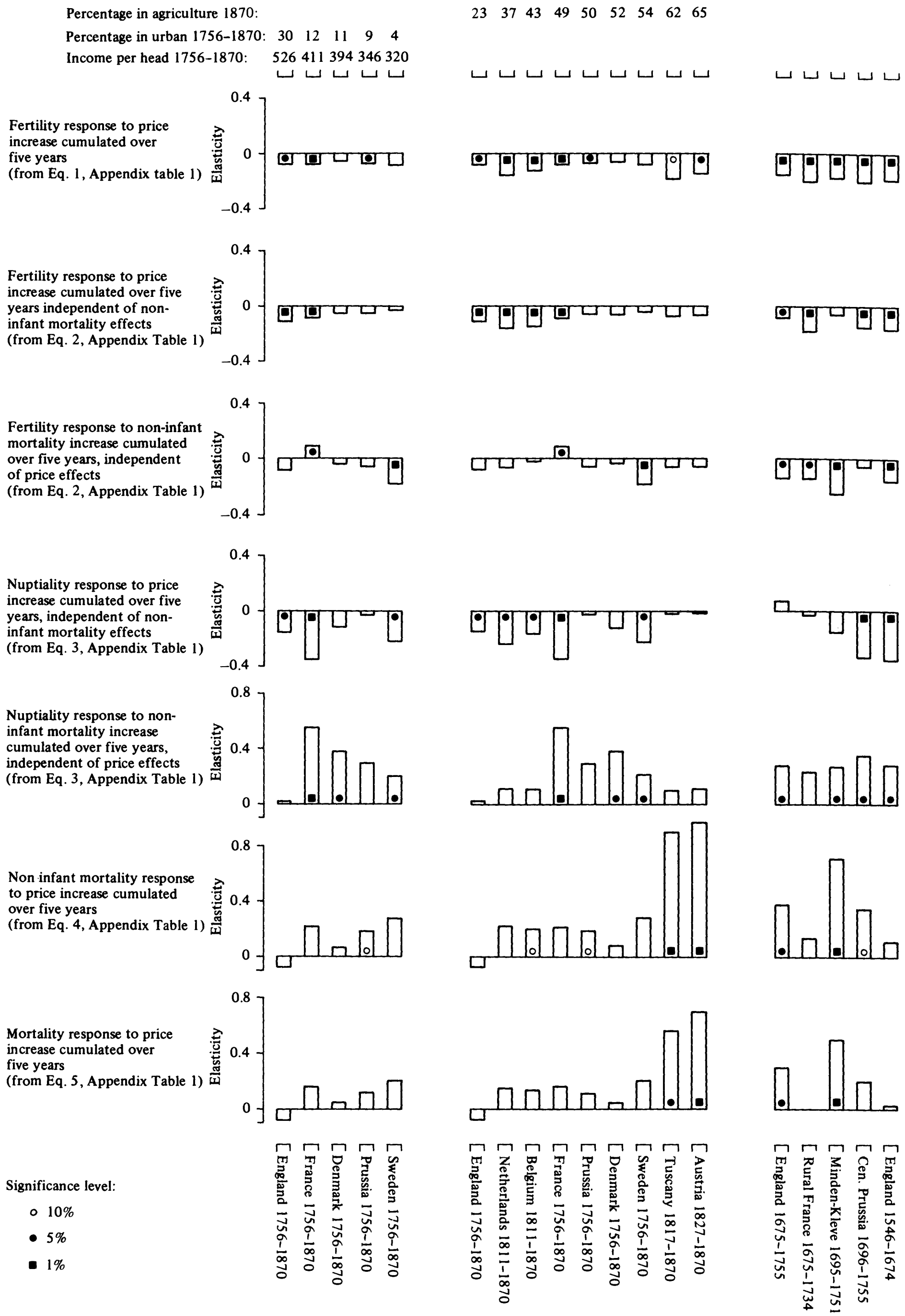

Figure 2. Fertility, nuptiality, and mortality responses to price increase cumulated over five years in pre-industrial European countries. Responses are displayed by level of income per head 1756–1870, percentage urban 1756–1870, and percentage of working population employed in agriculture in 1870.

The first two rows of Figure 2 show that the cumulative fertility response over five years to a price increase is negative in all countries. Looking at the first and second groups of the second row of bar graphs, the fertility response to a price increase seems to be slightly more pronounced according to levels of development. However, it is not safe to conclude that the strength of the fertility response becomes greater as economic welfare increases. The third group shows that the largest cumulative elasticities are found in rural France 1675–1734, Central Prussia 1696–1755, and England 1546–1674. It is possible that different mechanisms are involved concerning the biological and behavioural components of the fertility response discussed earlier. Fertility responses during the early periods may be a function of both biological and behavioural impacts on fertility. The responses of fertility to price fluctuations in the more affluent countries are probably less a function of biological changes and more a result of modifications in fertility behaviour.

Earlier research generally found that an increase in mortality significantly decreased fertility in England, France, Bombay Presidency, and Taiwan, although Eckstein *et al.* found only a weak negative relationship in Sweden, as did Galloway and Lee in Japan.[27] The fertility response to non-infant mortality independent of price effects is shown in Panel B of Figure 1. Not surprisingly, most of the action is at lag 0 with an average elasticity of about −0.090. This probably reflects a decline in fertility resulting from increased adult mortality and morbidity. The third row of bar graphs in Figure 2 shows the responses of fertility to variations in non-infant mortality. While the response in virtually all countries is negative, as expected, there seems to be no particular pattern for countries by level of development.

NUPTIALITY, PRICES, AND NON-INFANT MORTALITY

Periods of death should decrease or postpone marriages as the prospects for setting up a successful household are diminished. A surge in adult mortality would increase the stock of widows and widowers, leading to an increase in remarriages. An increase in adult mortality would also open up economic opportunities for those not yet married, allowing them to marry. On the negative side, higher mortality would be accompanied by an increase in mourning, which would tend to delay some marriages. The perception of increased mortality and morbidity might dampen the atmosphere of nuptial expectations, leading to postponement of marriage for some and perhaps permanently discouraging others from marrying.

In earlier studies, high prices were significantly associated with a decrease in marriages in England, France, and Sweden. Similarly, poor harvests in Croatia resulted in a decline in marriages.[28]

[27] For England see Lee, *op. cit.* in footnote 4, p. 375; Weir, *loc. cit.* in footnote 4, pp. 46–47; Bengtsson, *loc. cit.* in footnote 4, p. 22; and Schultz, *loc. cit.* in footnote 15, p. 38. For France see Richards, *op. cit.* in footnote 4, p. 377; Weir, *loc. cit.* in footnote 4, pp. 45 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 22; and Galloway, *loc. cit.* in footnote 4 (1986), p. 289. For Sweden see Eckstein *et al.*, *loc. cit.* in footnote 15, p. 306; Bengtsson, *loc. cit.* in footnote 4, p. 22; Schultz, *loc. cit.* in footnote 15, p. 38; and Galloway, *op. cit.* in footnote 4 (1987), pp. 112–134. For Bombay, Taiwan and Japan see Galloway and Lee, *loc. cit.* in footnote 15, Table 1.

[28] For England see Lee, *op. cit.* in footnote 4, p. 375; Weir, *loc. cit.* in footnote 4, pp. 46 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 21. For France see Richards, *op. cit.* in footnote 4, p. 382; Weir, *loc. cit.* in footnote 4, pp. 45 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 21; and Galloway, *loc. cit.* in footnote 4 (1986), p. 292. For Sweden see Bengtsson, *loc. cit.* in footnote 4, p. 21; and Galloway, *op. cit.* in footnote 4 (1987), pp. 105–111. For Croatia see Hammel, *loc. cit.* in footnote 15, p. 286.

The nuptiality regression analysis is similar to that of fertility using the detrended crude marriage rate, M, as the independent variable.

$$M_t = a + \sum_{k=0}^{4} b_k P_{t-k} + \sum_{k=0}^{4} c_k D^1_{t-k} + e_t. \tag{3}$$

Equation 3 in Appendix Table 1 shows the regression results. They reveal a wide range from country to country in the strength of the association between nuptiality, prices, and non-infant mortality (a proxy for adult mortality and morbidity). The proportion of nuptiality variance explained by prices and non-infant mortality ranges from around 20 per cent in France, Prussia, and Denmark to about 70 per cent in Austria and Belgium. Non-linear effects (not shown) were generally found to be not significant.

It is useful to display the combined responses of all the countries. In Panel C in Figure 1 is shown the nuptiality response to prices independent of non-infant mortality effects. On average, most of the effect of high prices on nuptiality occurs at lag 0 with an elasticity of -0.155, but there is considerable variation between countries. This negative elasticity at lag 0 is consistent with our hypothesis. Furthermore, high prices will on average tend to reduce marriages permanently, with a cumulative elasticity of -0.150 observed over the five-year period. There does not appear to be any strong regular pattern of nuptiality response to price changes for countries by economic development, as is shown in the fourth row of bar graphs in Figure 2, although the cumulative elasticities are nearly always negative.

Previous research found that an increase in non-infant mortality resulted in a significant decrease in nuptiality at lag 0, followed by a significant increase in marriages one year later in England. In France, marriages generally responded favourably to increased mortality, but the lag structure is sometimes difficult to interpret. A significant increase in marriages one year after an increase in mortality was found in Sweden.[29]

Panel D in Figure 1 shows that on average an increase in non-infant mortality tends to increase the marriage rate, but only after a year has elapsed. This delay is probably an indication of a mourning period for the widow or widower who eventually remarries. It has been demonstrated that adult mortality had little impact on first marriages of previously unmarried partners in England and Sweden;[30] thus the responses elicited are probably caused primarily by remarriages. The fifth row of Figure 2 shows that the cumulative elasticities of nuptiality responses to non-infant mortality increases are always positive, in accordance with the hypothesis. There is one seemingly peculiar response observed in the first group of the fifth row of bar graphs. The cumulative elasticity for England during the period 1756–1870 is virtually nil, while the responses in France, Denmark, Prussia, and Sweden increase with income and urbanization. It appears that the English were less inclined to remarry as a result of increased mortality.

[29] For England see Lee, *op. cit.* in footnote 4, p. 375; Weir, *loc. cit.* in footnote 4, pp. 46 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 21. For France see Richards, *op. cit.* in footnote 4, p. 382; Weir, *loc. cit.* in footnote 4, pp. 45 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 21; and Galloway, *loc. cit.* in footnote 4 (1986), p. 292. For Sweden see Bengtsson, *loc. cit.* in footnote 4, p. 21; and Galloway, *op. cit.* in footnote 4 (1987), pp. 105–111.

[30] For England see Lee, *op. cit.* in footnote 4, p. 362. For Sweden see Galloway, *op. cit.* in footnote 4 (1987), pp. 105–111.

MORTALITY AND PRICES

High grain prices can lead to increased mortality in a number of ways. The most obvious is through an increase in outright starvation. An increase in mortality can also result from increased susceptibility to various diseases as a result of malnourishment. May and Anderson note 'of special importance are the effects that can arise from the now widely recognized fact that the impact of an infection is often related to the nutritional state of the host. Broadly speaking, malnourished hosts have lowered immunological competence, and are less able to withstand the onslaught of infection. The effective pathogenicity of a parasite therefore tends to increase as host density rises to a level where competition for available food resources is severe'.[31] High grain prices would probably be associated with increased migration within the countryside, and from rural to urban areas, as individuals search for food obtained through employment, charity, or theft. This would tend to increase the frequency of interaction between different members of the population, leading in turn to an increase in the frequency of epidemics.

It is difficult to separate the direct effects on mortality of a decrease in food supply, mainly starvation and malnutrition, from other effects which involve interactions of malnutrition, impaired immunocompetence, increased migration, and an increase in infectious disease by using historical data.[32] Whatever the opinions of the importance of the various mechanisms might be, it is generally agreed that a poor harvest, and accompanying high grain prices, usually increased mortality in pre-industrial economies.

Earlier research has shown a significant positive correlation between grain prices and mortality in England before the middle of the eighteenth century but not later. In France mortality also responded positively to prices before 1739, but was unpredictable afterwards. A significant positive relationship between prices and mortality, mainly at early lags, was found in Sweden. These results were corroborated by an increase in mortality associated with a decrease in the real wage found in Sweden and poor harvests in Croatia. Outside Europe, high grain prices were significantly associated with increased mortality in Japan and Bombay Presidency, but not in Taiwan.[33]

[31] R. M. May and R. M. Anderson, 'Population biology of infectious diseases: part II', *Nature*, **280** (1979), p. 460.

[32] N. S. Scrimshaw, C. E. Taylor, and J. E. Gordon, *Interactions of Nutrition and Infection* (Geneva: World Health Organization, 1968); A. E. Axelrod, 'Nutrition in relation to immunity', in *Modern Nutrition in Health and Disease*, ed. R. S. Goodhart and M. E. Shils (Philadelphia: Lea and Febiger, 1980), pp. 578–591; S. E. Snyderman, 'Nutrition in infancy and adolescence', in Goodhart and Shils, *ibid.*, pp. 753–780; R. Martorell and T. J. Ho, 'Malnutrition, morbidity, and mortality', *Population and Development Review*, Supplement to Volume **10** (1984), pp. 49–68; A. G. Carmichael, 'Infection, hidden hunger, and history', in *Hunger and History, the Impact of Changing Food Production and Consumption Patterns on Society*, ed. R. I. Rotberg and T. K. Rabb (Cambridge: Cambridge University Press, 1985), pp. 51–66; M. Livi-Bacci, 'The nutrition-mortality link in past times: a comment', in Rotberg and Rabb, *ibid.*, pp. 95–100; T. McKeown, 'Food, infection, and population', in Rotberg and Rabb, *ibid.*, pp. 29–50; C. E. Taylor, 'Synergy among mass infections, famines, and poverty', in Rotberg and Rabb, *ibid.*, pp. 285–304; L. A. Tilly, 'Food entitlement, famine, and conflict', in Rotberg and Rabb, *ibid.*, pp. 135–152; and S. C. Watkins and E. van de Walle, 'Nutrition, mortality, and population size: Malthus' court of last resort', in Rotberg and Rabb, *ibid.*, pp. 7–28.

[33] For England see Lee, *op. cit.* in footnote 4, p. 375; Weir, *loc. cit.* in footnote 4, pp. 46–47; Bengtsson, *loc. cit.* in footnote 4, p. 15; and Schultz, *loc. cit.* in footnote 15, p. 39. For France see Richards, *op. cit.* in footnote 4, p. 380; Weir, *loc. cit.* in footnote 4, pp. 45 and 47; Bengtsson, *loc. cit.* in footnote 4, p. 15; and Galloway, *loc. cit.* in footnote 4 (1986), p. 295. For Sweden see Fridlizius and Ohlsson, *op. cit.* in footnote 4, p. 307; Eckstein *et al.*, *loc. cit.* in footnote 15, p. 306; Bengtsson, *loc. cit.* in footnote 4, p. 15; Bengtsson and Ohlsson, *loc. cit.* in footnote 15, p. 317; and Schultz, *loc. cit.* in footnote 15, p. 39. For Croatia see Hammel, *loc. cit.* in footnote 15, p. 286. For Bombay, Taiwan, and Japan see Galloway and Lee, *loc. cit.* in footnote 15, Table 2. For age-specific and cause-specific mortality responses to price changes in London and Sweden see Galloway, *op. cit.* in footnote 4 (1987), pp. 135–192.

The equations used in the mortality analysis are shown below. Both detrended non-infant mortality (D^1 in Equation 4) and detrended total mortality (D in Equation 5) are independent variables. Non-infant mortality removes the confounding effect of increases in infant deaths resulting from increases in births as a result of lower prices.

$$D_t^1 = a + \sum_{k=0}^{4} b_k P_{t-k} + e_t. \quad (4)$$

$$D_t = a + \sum_{k=0}^{4} b_k P_{t-k} + e_t. \quad (5)$$

Details of the regression results can be found in Equations 4 and 5 of Appendix Table 1. These suggest that price fluctuations typically explain only between 20 and 40 per cent of the variance in non-infant mortality. Non-linear effects (not shown) are significant in about half the countries and the 'price runs' variable seems to be important in some of the poorer areas.

In Panels E and F of Figure 1 we show the large variation in patterns of response of mortality to price changes between countries. On average we find a prolonged positive elasticity from lag 0 to lag 2, tapering off to virtually nil at lags 3 and 4. While the proportion of mortality variance explained is relatively low, the size of the mortality responses is generally greater than that of fertility and nuptiality responses, particularly when cumulated over five years.

It has been suggested that the higher the level of economic welfare, the more muted will be the response of mortality to price changes. The bottom two rows of Figure 2 support this hypothesis. The cumulative effect of price fluctuations on mortality appears to be reduced as income and urbanization levels increase between 1756 and 1870. In fact, there is a curious negative response in England. In other words, as prices rise, mortality rates in England decline during this period. This counter-intuitive finding for England is corroborated by Lee.[34] An explanation for this apparently unusual response will be found in the following section.

The bottom two rows of Figure 2 also show the change in mortality response to price fluctuations in England for three periods: 1546–1674, 1675–1755, and 1756–1870. The cumulative non-infant mortality responses are 0.107, 0.380, and −0.086, respectively from Appendix Table 1. The middle period, 1675–1755, was characterized by climatic deterioration[35] and lower life expectancy,[36] suggesting lower living standards.[37]

THE SHORT-TERM PREVENTIVE AND POSITIVE CHECKS

Malthus proposed two checks to population growth in response to declining food supply: the preventive check which operated through fertility, and the positive check which reflected the mortality response. If fertility is represented by the crude birth rate, and mortality by the crude death rate, then in a closed population the change in the

[34] Lee, *op. cit.* in footnote 4, p. 376.

[35] See Galloway, *loc. cit.* in footnote 2, pp. 1–24.

[36] Life expectancy in England was 36.2 from 1546 to 1674, 34.0 from 1675 to 1755, and 38.2 from 1756 to 1870. Data are from Wrigley and Schofield, *op. cit.* in footnote 4, p. 230.

[37] Lee, using periods 1548–1640, 1641–1745, and 1746–1834, found a consistent decline in the non-infant mortality responses to price changes of 0.347, 0.103, and −0.133, respectively (from Lee, *op. cit.* in footnote 4, p. 376). The differences in our results for the two periods can be explained statistically through an analysis of the overlapping period 1641–74, which yielded a strong negative response of mortality to prices of −0.277 cumulated over five years. This suggests unusually strong influences of other factors on mortality during this short period, perhaps epidemics of plague or other diseases, climatic extremes, or the impact of the civil wars.

Table 2. *Preventive and positive checks: the responses of fertility and mortality over five years to a one standard deviation (21.4%) increase in grain prices at lag 0*

					Preventive check				
Place	Period	Percentage of pop. in agri. in 1870 (1)	Income per Head 1756–1870 (1970 $US) (2)	Percentage Urban 1756–1870 (3)	Avg. CBR (4)	Lag sum price (5)	CBR response to a 21.4% price increase (5) × 0.214 (6)	Change in CBR (4) × (6) (7)	New CBR (4) + (7) (8)
England	1756–1870	22.7*	526†	30.2†	37.0	−0.082	−0.018	−0.6	36.4
Netherlands	1811–1870	37.0	—	—	33.9	−0.163	−0.035	−1.2	32.7
Belgium	1811–1870	43.0	—	—	32.5	−0.130	−0.028	−0.9	31.6
France	1756–1870	49.2	411	11.8	32.8	−0.079	−0.017	−0.6	32.2
Prussia	1756–1870	49.5‡	346‡	8.8‡	40.0	−0.070	−0.015	−0.6	39.4
Denmark	1756–1870	51.7	394	10.7	31.0	−0.055	−0.012	−0.4	30.6
Sweden	1756–1870	53.9	320	4.2	32.6	−0.087	−0.019	−0.6	32.0
Tuscany	1817–1870	62.0§	—	—	38.0	−0.182	−0.039	−1.5	36.5
Austria	1827–1870	65.0	—	—	38.2	−0.150	−0.032	−1.2	37.0
England	1675–1755	—	—	—	32.4	−0.152	−0.033	−1.1	31.3
England	1546–1674	—	—	—	32.4	−0.177	−0.038	−1.2	31.2

		Positive check					Population growth rate (percent)			
				CDR response to a 21.4% Price Increase						Ratio of change in CDR to change in CBR
Place	Period	Avg. CDR (9)	Lag Sum price (10)	(10) × 0.214 (11)	Change in CDR (9) × (11) (12)	New CDR (9) + (12) (13)	Average (4) − (9) (14)	New (8)–(13) (15)	Difference (15)–(14) (16)	(12)/(7) (17)
England	1756–1870	24.9	−0.094	−0.020	−0.5	24.4	1.21	1.20	−0.01	0.77
Netherlands	1811–1870	25.7	0.147	0.031	0.8	26.5	0.82	0.62	−0.20	−0.68
Belgium	1811–1870	24.3	0.131	0.028	0.7	25.0	0.82	0.66	−0.16	−0.75
France	1756–1870	29.1	0.167	0.036	1.0	30.1	0.37	0.21	−0.16	−1.88
Prussia	1756–1870	30.2	0.114	0.024	0.7	30.9	0.98	0.85	−0.13	−1.23
Denmark	1756–1870	24.3	0.056	0.012	0.3	24.6	0.67	0.60	−0.07	−0.80
Sweden	1756–1870	24.9	0.205	0.044	1.1	26.0	0.77	0.60	−0.17	−1.80
Tuscany	1817–1870	28.7	0.567	0.121	3.5	32.2	0.93	0.43	−0.50	−2.35
Austria	1827–1870	31.9	0.699	0.150	4.8	36.7	0.63	0.03	−0.60	−3.89
England	1675–1755	29.3	0.296	0.063	1.9	31.2	0.31	0.02	−0.29	−1.76
England	1546–1674	26.4	0.028	0.006	0.2	26.6	0.60	0.46	−0.14	−0.13

Note: The analysis of the population growth rate assumes a closed population.

Sources: Columns (1), (2), (3), (4) and (9) are from Table 1. Column (5) is from Equation 1 in Appendix Table 1. Column (10) is from Equation 5 in Appendix Table 1.

* United Kingdom. † England and Wales. ‡ Germany. § Italy.

population growth rate as a result of a change in food supply (usually reflected by fluctuations in grain prices) is simply the difference between the crude birth rate response and the crude death rate response. For purposes of this analysis the preventive check will be determined by the fertility response to price changes from Equation 1, and the positive check will be based on the mortality response to price changes from Equation 5, in order ultimately to estimate the response of the population growth rate.[38]

The procedure is outlined in Table 2. In order to clarify the process, the columns have been labelled by numbers in parentheses. The nine countries for which crude birth rates and crude death rates are available together with the periods covered are shown. The two earlier periods for England are also shown; however, the analysis will focus on the nine countries during the period after 1756. The three measures of economic development are found in Columns (1), (2), and (3). The cumulative response over five years of fertility to a price increase (5) is multiplied by the average standard deviation in prices between the nine countries, including the two earlier periods for England. This average standard deviation in prices happens to be 21.4 per cent and is fairly typical as shown in Table 1. This price-induced change in the crude birth rate (6) is multiplied by the average crude birth rate during the period under consideration for each country (4). The product (7) is the actual numerical change in the crude birth rate over five years resulting from a price increase of one standard deviation. This ranges from -0.6 to -1.5. The resulting new crude birth rate is shown in Column (8). The same procedure is used with crude death rates in Columns (9) to (13). The changes in the crude death rate as a result of a price increase (12) range from the unusual -0.5 in England to 4.8 in Austria.

With this information it is possible to assess the magnitude of the numerical change in the population growth rate as a result of variations in grain prices. In this part of the analysis we assume a closed population. The average population growth rate is shown for each country in Column (14). It is simply the difference between the average crude birth rate (4) and the average crude death rate (9). The figures are consistent with previous work, showing England to be the most rapidly growing country, and France the slowest during this period.[39] The population growth rate resulting from an increase in prices (15) of one standard deviation is the difference between Column (8) and Column (13). The difference (16) between Columns (15) and (14) is the numerical change in the population growth rate five years after an increase in prices of one standard deviation. This ranges from a low of only -0.01 in England, virtually no change, to a substantial -0.60 in Austria.

Finally it is possible to estimate the relative strengths of the positive and preventive checks. This is done by taking the ratio of the price-induced change in the crude death rate (12) to the price-induced change in the crude birth rate (7). In this analysis the positive check dominates the preventive check if this ratio (17) falls below -1. If the ratio is greater than -1, the preventive check dominates. As shown in Column (17), only in England, the Netherlands, Belgium, and Denmark is the preventive check dominant. The odd positive ratio for England is a result of the unusual change of -0.5 in the crude death rate in Column (12).

These results can be assessed in a clearer fashion by reference to Figures 3 to 5. Figure 3 shows six panels labelled A–F. The x-axis in each panel is the percentage of population

[38] Malthus probably intended the preventive check to refer to strictly behavioural fertility responses to scarcity. However, the differences between biological and behavioural fertility responses are difficult to distinguish in the empirical analysis. As a consequence I implicitly include both effects in the preventive check.

[39] E. A. Wrigley, 'The growth of population in eighteenth-century England: a conundrum resolved', *Past and Present*, **98** (1983), pp. 121–150.

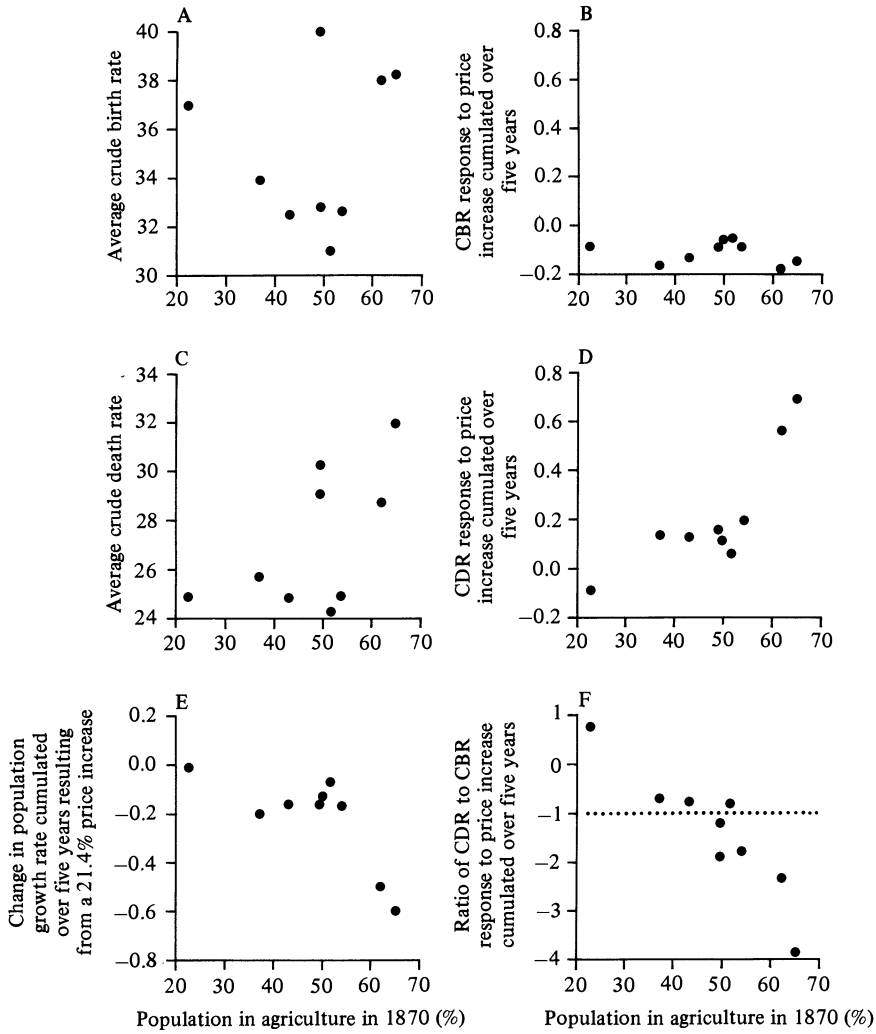

Figure 3. The preventive check, positive check, and percentage of the population in agriculture in European countries in 1870. (Data are from Table 2.)

employed in agriculture in 1870, a measure that has been used as a proxy for economic development. The data points represent the nine countries for which data are available after 1756. Panel A shows that there is little relationship between crude birth rate and economic development. Panel C indicates a moderate negative relationship between the crude death rate and economic development. The cumulative five-year response of fertility to a price increase, from Column (5) in Table 2, is shown in Panel B. There is little association with development, and the elasticities are rather small. We may conclude that the preventive check is about the same in all the countries. Panel D shows the cumulative five-year response of mortality to a price increase, from Column (10) in Table 2, using the same scale as Panel B. There is a clearly discernible pattern. The greater the percentage of population in agriculture the greater the elasticity, i.e. the greater the positive check. The more industrialized the country, the lower the elasticity. Indeed, England's negative elasticity of −0.094 appears reasonable when plotted along these lines. This finding suggests that after a certain level of development has been

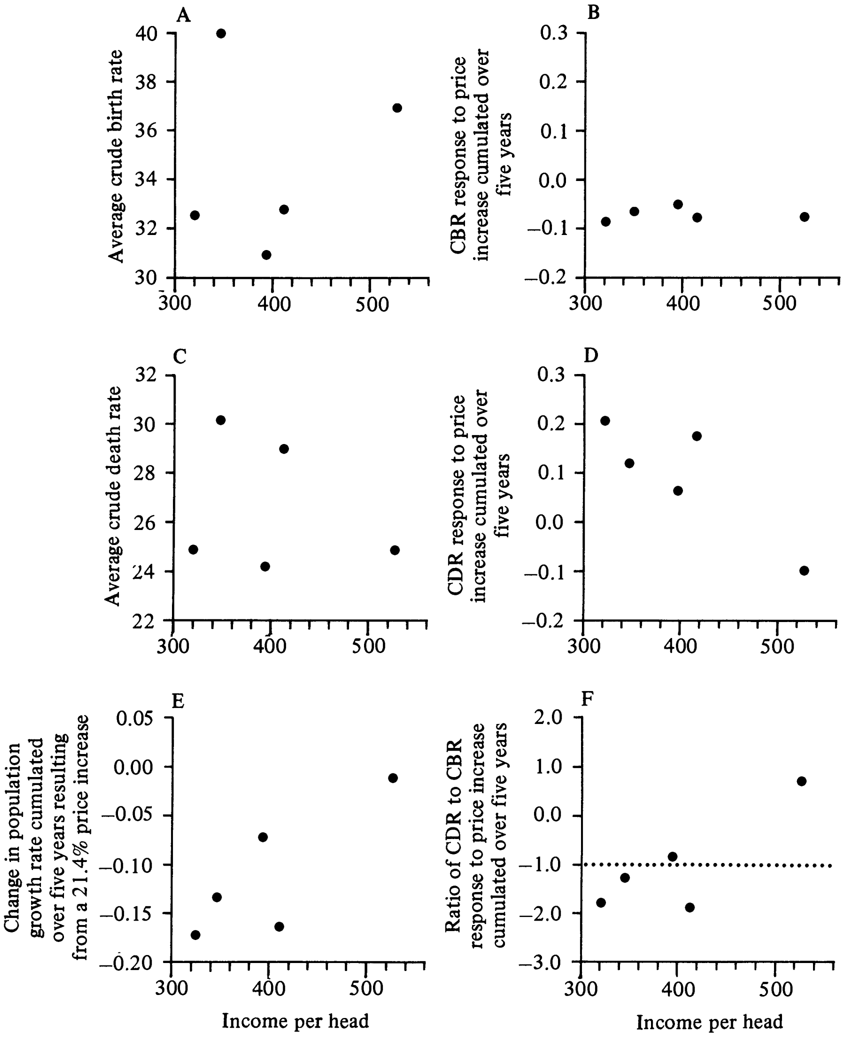

Figure 4. The preventive check, positive check, and real income per head in 1970 U.S. dollars in England, France, Denmark, Prussia, and Sweden 1756–1870. (Data are from Table 2.)

attained, an annual increase in living standards might tend to increase the annual mortality rate, perhaps as a result of an increase in riskier activities.

Part E of Figure 3 shows the change in population growth rate five years after an increase of one standard deviation in grain prices. The data are from Column (16) in Table 2. It is clear that the less developed the country the more pronounced the negative impact of price increases on population growth. As we noted earlier, the population growth rate of England is barely affected by changes in prices. Finally Panel F represents the ratio of the positive check to the preventive check from Column (17) in Table 2. Countries lying above the dotted line are dominated by the preventive check. These are generally the more industrialized countries. Those below the dashed line are dominated by the positive check. They are the more agricultural countries. The strength of this relationship is remarkable. It may be concluded that the positive check is the primary factor in the determination of the differences between countries in annual changes in the population growth rate resulting from annual changes in grain prices.

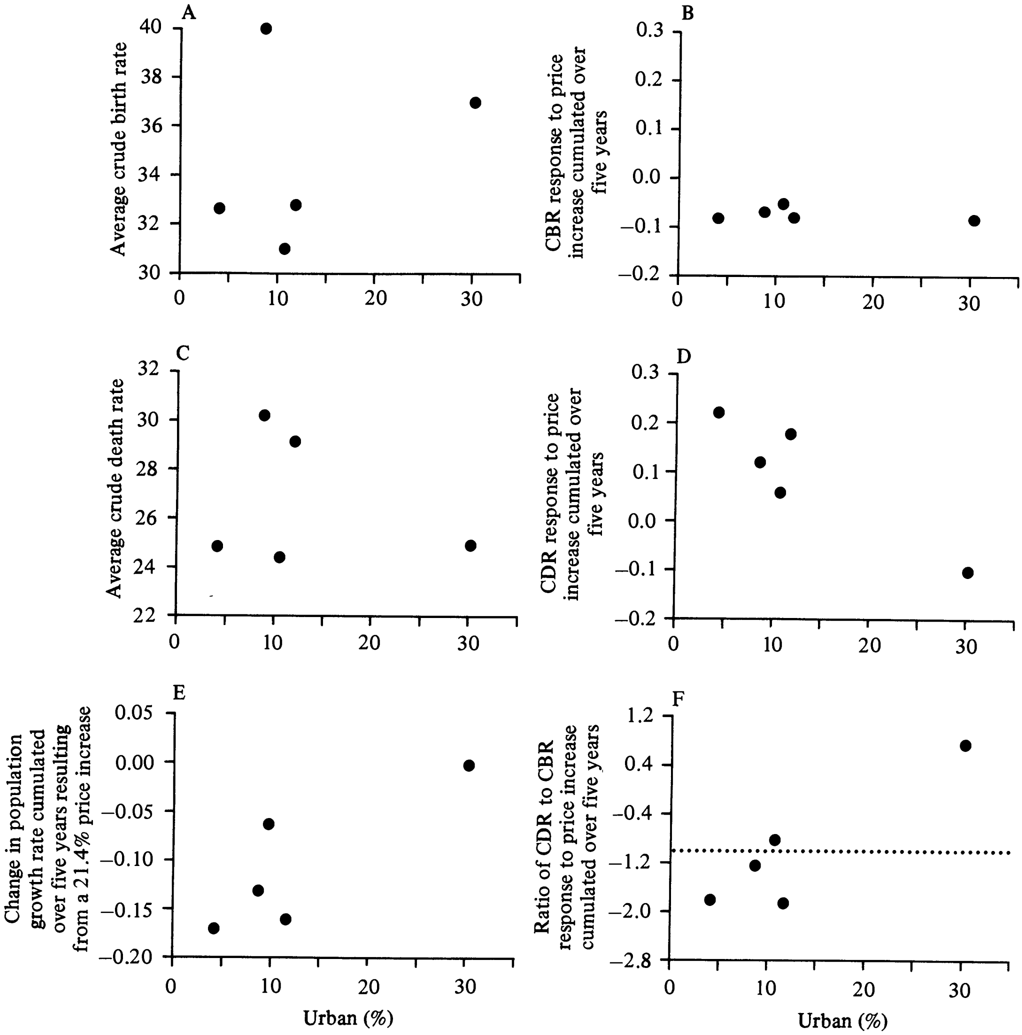

Figure 5. The preventive check, positive check, and percentage urban in England, France, Denmark, Prussia and Sweden 1756–1870. (Data are from Table 2.)

Figure 4 is similar to Figure 3 but uses average income per head 1756–1870 along the x-axis and restricts the data to the five countries having the identical period of 1756–1870. These countries are England, France, Denmark, Prussia, and Sweden. In Figure 5 the same information is plotted for these five countries using average percentage urban 1756–1870 as the x-axis. Figures 3, 4, and 5 show essentially the same patterns. Figures 4 and 5 suggest that population growth in France appears to be unusually influenced by the positive check, given its level of income and urbanization relative to other countries.

CONCLUSIONS

It is possible to gain some insight into the demographic regimes of pre-industrial European countries given only vital rates, grain prices, some measures of economic development, and an appropriate method. Fertility was highly sensitive to grain price fluctuations (the short-term preventive check) in most of pre-industrial Europe. The magnitude and timing of the response of fertility to price variations were similar across all countries and all periods.

On the other hand, the magnitude and timing of the response of mortality to variations in grain prices (the short-term positive check) were considerably different in different countries and seemed to vary in accord with industrialization, income levels, and urbanization. Generally the more advanced the level of development, the more muted the mortality response to fluctuations in grain prices.

Among the countries analysed, the positive check was found to be the major determinant of differences in the magnitude of change in the population growth rate resulting from high prices. The strength of the positive check relative to the preventive check appears to diminish with economic development.

Finally it should be noted that England was unique in being the first country in Europe, and probably the world, to escape the bonds of the positive check to population growth. Indeed, the population growth rate of England 1756–1870, the most developed country in Europe at the time, was hardly affected by changes in prices. Conversely, population growth rates in Austria and Tuscany during the nineteenth century, the two poorest countries analysed, were profoundly influenced by price fluctuations.

DATA APPENDIX

(All data are for the calendar year unless stated otherwise.)

Percentage of working population employed in agriculture in 1870

Data are from A. Maddison, *Phases of Capitalist Development* (Oxford: Oxford University Press, 1982), p. 205.

Income per head 1756–1870

Data are average annual gross domestic product per head at 1970 United States prices in dollars from Maddison, *ibid.*, p. 8. Maddison presents data for England and Wales and France for 1700, 1820, and 1870. I calculated the average annual percentage increase in income per head during each of the two periods (1700–1820 and 1820–70) in order to obtain estimates of annual income per head from 1700 to 1870. I then took the average of these annual estimates from 1756 to 1870 for each country.

For Germany, Denmark, and Sweden Maddison shows data for 1820 and 1870 only. To estimate average annual income per head between 1700 and 1820, I calculated the average annual percentage increase in income per head of England and Wales, France, and Netherlands combined from 1700 to 1820. I then applied this growth rate 1756–1820 to the income data in 1820 for Germany, Denmark, and Sweden to arrive at an estimate of their respective average annual incomes per head 1756–1820. The average annual incomes per head for Germany, Denmark, and Sweden 1756–1870 were then calculated in the manner described above.

Percentage urban 1756–1870

Percentage urban is the number of persons living in cities with more than 10,000 inhabitants, multiplied by 100, and divided by the total population of the country, as suggested by J. DeVries, *European Urbanization 1500–1800* (Cambridge: Harvard University Press, 1984), p. 22. The average percentage urban 1756–1870 for England and Wales, France, and Germany is calculated by first estimating by interpolation the average annual percentage urban during the periods 1750–1800, 1800–1850, and 1850–1890 from urban and total country population data presented by DeVries, *ibid.*, pp. 36, 45–46, 306–337. These annual estimates are then averaged over the period 1756–1870 for each country.

DeVries combines the data for Denmark and Sweden. I have calculated the percentage urban in Denmark 1756–1870 from population data for urban and total Denmark 1750–1800 from

A. Lassen, *Fald og Fremgang, Traek af Befolkningsudviklingen i Danmark 1645–1960* (Aarhus: Universitetsforlaget, 1965), pp. 530, 537 and 1800–1870 from Statistiske Departement, *Befolkningsudvikling og Sundhedsforhold 1901–60* (Kobenhavn, 1966), pp. 11–13, 16–17. The Swedish data 1750–1870 are from Statistiska Centralbyrån, *Historisk Statistik för Sverige, Del 1. Befolkning Andra Upplagen 1720–1967* (Stockholm: Beckman, 1969), pp. 49, 61–62, 91–95. The data are interpolated where necessary to arrive at annual estimates of percentages urban. These annual estimates are then averaged over the period 1756–1870 for each country.

England 1539–1875

Crude birth, marriage and death rates 1668–1871 are taken from E. A. Wrigley and R. S. Schofield, *The Population History of England 1541–1871, A Reconstruction* (Cambridge: Harvard University Press, 1981), pp. 503–535. Rates for 1872–5 are from B. R. Mitchell, *European Historical Statistics 1750–1975* (New York: Facts on File, 1981), p. 123. Rates for 1539–1679 for the harvest year are from Wrigley and Schofield, *ibid.*, pp. 503–535.

Infant mortality rate 1539–1838 is estimated from life expectancy and life table data from Wrigley and Schofield, *ibid.*, pp. 230, 714. Infant mortality rate 1839–75 is from Mitchell, *ibid.*, pp. 137, 139.

Wheat prices 1664–1875 for the calendar year are based on the following two series: Winchester wheat prices 1664–1817 from W. Beveridge *Prices and Wages in England from the Twelfth Century to the Nineteenth Century* (London: Longmans, Green and Co., 1939), vol. 1, pp. 81–84 and England wheat prices 1771–1875 from B. R. Mitchell and P. Deane, *Abstract of British Historical Statistics* (Cambridge: University Press, 1962), pp. 488–489. Where the two series overlap, 1776–1812 after detrending, they are highly correlated ($r = 0.96$) with similar coefficients of variation. Wheat prices 1535–1679 for the harvest year are based on the following two series: England wheat prices 1535–1649 from P. Bowden, 'Price of agricultural commodities: annual averages', in *The Agrarian History of England and Wales, Volume IV, 1500–1640*, ed. J. Thirsk, (Cambridge: Cambridge University Press, 1967), pp. 818–821 and Winchester wheat prices 1630–79 from Beveridge, *ibid.*, vol. 1, p. 81. Where the two series overlap, 1635–44 after detrending, they are highly correlated ($r = 0.92$) with similar coefficients of variation.

Netherlands 1804–75

Crude birth, marriage and death rates 1804–39 are taken from E. W. Hofstee, *De Demografische Ontwikkeling van Nederland in de Eerste Helft van de Negentiende Eeuw* (Nederlands Interuniversitair Demografisch Instituut, 1978), pp. 196, 198, 200. Rates for 1840–75 are from Mitchell, *ibid.*, pp. 116, 120. Where Hofstee's and Mitchell's series of crude birth rates overlap, 1840–50, Mitchell's series is nearly always equal to 0.94 that of Hofstee. The same is true for the series of crude death rates with the factor being 0.92. As a consequence Hofstee's estimates from 1804 to 1839 have been adjusted, using these factors.

Infant mortality rate 1804–75 is from Mitchell, *ibid.*, pp. 137, 139. Infant mortality data are available only from 1840–75, so the infant mortality rate is estimated to be 182 for the period 1804–39. This is the average infant mortality rate 1840–9.

Rye prices 1800–75 are Amsterdam rye prices from N. W. Posthumus, *Inquiry into the History of Prices in Holland* (Leiden: Brill, 1946), vol. 1, pp. 22–23. Some gaps in the price series are filled using changes in Ghent rye prices from C. Verlinden, *Dokumenten voor de Geschiedenis van Prijzen en Lonen in Vlaanderen en Brabant* (Brugge: De Tempel, 1972), vol. 3, pp. 100–113.

Belgium 1804–75

Crude birth, marriage and death rates 1804–50 are taken from Hofstee, *ibid.*, pp. 197, 199, 201. Rates for 1851–75 are from Mitchell, *ibid.*, p. 118.

Infant mortality rate 1804–75 is from Mitchell, *ibid.*, pp. 137, 138. Infant mortality data are available only from 1834–75, so the infant mortality rate is estimated to be 174 for the period 1804–33. This is the average infant mortality rate 1834–43.

Rye prices 1800–75 are Ghent rye prices from Verlinden, *ibid.*, vol. 3, pp. 100–113.

France 1749–1875

Crude birth, marriage and death rates 1749–1839 are taken from Institut National d'Etudes Démographiques 'Sixième rapport sur la situation démographique de la France', *Population*, **32**, 2 (1977), pp. 332–333. Rates for 1840–75 are from Mitchell, *ibid.*, pp. 116, 119.

Infant mortality rate 1749–1829 is from Institut National d'Etudes Démographiques, *ibid.*, pp. 332–333. Infant mortality rate 1830–75 is from Mitchell, ibid., pp. 137, 138.

Wheat prices 1745–1875 are France wheat prices from E. Labrousse, *Le Prix du Froment en France au Temps de la Monnaie Stable (1726–1913)* (Paris: SEVPEN, 1970), pp. 9–10. The four-year gap in this series 1793–96 is filled using data from C.-E. Labrousse, *Esquisse du Mouvement des Prix et des Revenus en France au XVIII^e Siècle* (Paris: Librairie Dalloz, 1933), p. 105.

Prussia 1749–1875

Crude birth, marriage and death rates 1749–1805 are from O. Behre, *Geschichte der Statistik in Brandenburg-Preussen bis zur Gründung des Königlichen Statistischen Bureaus* (Berlin: Heymanns, 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 neighbouring region. The sum of the vital events is calculated and divided by the population for each year. Deaths probably include stillbirths which should be removed. This is done by multiplying the number of births in a given year by 0.039, the estimated stillbirth rate in Prussia 1816–70 from Königliches Statistisches Bureau, *Preussische Statistik*, **188** (1904), pp. 12–13, and subtracting this result from deaths. Rates for 1806–15 are based on data for the city of Berlin from Statistisches Amt, *Statistisches Jahrbuch der Stadt Berlin*, **34** (1920), pp. 67, 70, 101, and for the city of Frankfurt from H. Bleicher, *Statistische Beschreibung der Stadt Frankfurt am Main und ihrer Bevölkerung, II Theil, die innere Gliederung der Bevölkerung* (Frankfurt a.M.: Sauerländer, 1895), p. 237. No data were found for any area of Prussia at a more aggregated level for these turbulent years. The annual estimates for Prussia for the years 1806–15 are made by applying the average annual percentage change in vital events in Berlin and Frankfurt during the period to the Prussia data beginning with 1805. Rates for 1816–75 are from Königliches Statistisches Bureau, *ibid.*, **188** (1904), pp. 12–13.

Infant mortality rate 1749–1815 is estimated to be 188 which was the average rate in Prussia 1816–70 from Königliches Statistisches Bureau, *ibid.*, **48** (1879), p. 97, and *ibid.*, **188** (1904), p. 121. Infant mortality rate 1816–75 is from Königliches Statistisches Bureau, *ibid.*, **48** (1879), p. 97, and *ibid.*, **188** (1904), p. 121. Infant mortality rate is interpolated for 1867–74 because infant mortality data were not collected during this period according to Königliches Statistisches Bureau, *ibid.*, **233** (1912), p. 414.

Rye prices 1745–1875 are the average of Berlin, Frankfurt, and Danzig rye prices. The Berlin rye prices are from F. W. C. Dieterici, 'Ueber die Marktpreise des Getreides in Berlin seit dem Jahre 1624', *Mittheilungen des Statistischen Bureau's in Berlin*, **6** (1853), pp. 92–95, with gaps filled using Berlin rye prices from W. Naudé and A. Stalweit, *Die Getreidehandelspolitik und Kriegsmagazinverwaltung Preussens 1740–1756* (Berlin: Parey, 1910), vol. 3, pp. 624–631, A. Stalweit, *Die Getreidehandelspolitik und Kriegsmagazinverwaltung Preussens 1756–1806* (Berlin: Parey, 1931), vol. 4, pp. 647–651, and Königliches Statistisches Bureau, *Tabellen und Übersichten zum Statistischen Atlas für den Preussischen Staat* (Berlin, 1905), p. 69. The Frankfurt rye prices are from M. J. Elsas, *Umriss einer Geschichte der Preise und Löhne in Deutschland* (Leiden: Sijthoff, 1949), vol. 2b, pp. 112–114, and Königliches Statistisches Bureau, *ibid.*, p. 69. The Danzig rye prices are from T. Furtak, 'Preisgeschichte Danzigs 1701–1815', *Badanai z Dziejow Spolecznych i Gospodarczych*, **22** (1935), pp. 121–124, and Königliches Statistisches Bureau, *ibid.*, p. 69.

Denmark 1749–1875

Crude birth and death rates 1749–1800 and crude marriage rates 1775–1800 are from A. Jensen, 'Befolkningsforhold i de nordiske lande i det 18 aarhundrede', *Nationalokonomisk Tidskrift*, **73** (1935), p. 14. Rates 1801–75 are from Statistiske Departement, *ibid.*, pp. 16–17.

Infant mortality rate 1749–1801 is estimated to be 225 from H. C. Johansen, 'The position of the old in the rural household in a traditional society', *Scandinavian Economic History Review*, **24**, 2 (1976), p. 133. Infant mortality rate 1802–34 is interpolated from 225 to 152. The rate of 152 is the infant mortality rate in 1835 from Mitchell, *ibid.*, p. 137. Infant mortality rate 1835–75 is from Mitchell, *ibid.*, pp. 137, 138.

Rye prices 1745–1875 are based on the following three series: Copenhagen rye prices 1745–1800 from A. Friis and K. Glamann, *A History of Prices and Wages in Denmark 1660–1800* (London: Longmans, Green and Co., 1958), pp. 209–224, with gaps filled based on changes in Rendsburg rye prices from E. Waschinski, *Währung, Preisentwicklung und Kaufkraft des Geldes in Schleswig-Holstein von 1226–1864* (Neumünster: Wachholtz, 1959), p. 164; Rendsburg rye prices 1801–63 from Waschinski, *ibid.*, pp. 253–255; and Denmark rye prices 1864–75 from J. Pedersen and O. S. Petersen, *An Analysis of Price Behaviour during the Period 1855–1913* (Copenhagen: Levin and Munksgaard, 1938), p. 244. The series are highly correlated where they overlap.

Sweden 1749–1875

Crude birth, marriage and death rates 1749–1875 are from Statistiska Centralbyrån, *ibid.*, pp. 90–95.

Infant mortality rate 1749–50 is estimated to be 205, which is the average infant mortality rate 1751–60 from Statistiska Centralbyrån, *ibid.*, p. 91. Infant mortality rate 1751–1875 is from Statistiska Centralbyrån, *ibid.*, pp. 90–95.

Rye prices 1745–1875 are Sweden rye prices based on the following two series: Sweden rye 1745–1829 from L. Jörberg, *A History of Prices in Sweden 1732–1914* (Lund: Gleerup, 1972), vol. 1, pp. 632–634, and Sweden rye 1830–75 from G. Myrdal, *The Cost of Living in Sweden 1830–1930* (Stockholm: Norstedt, 1933), pp. 200, 202.

Tuscany 1810–75

Crude birth, marriage and death rates are from P. Bandettini, *La Popolazione della Toscana dal 1810 al 1959* (Firenze: Scuola di Statistica della Università Firenze, 1961), p. 12.

Infant mortality rate 1810–62 is estimated to be 226, which is the average infant mortality rate in Italy 1863–72 from Mitchell, *ibid.*, p. 138. Infant mortality rate 1863–75 is from Mitchell, *ibid.*, p. 138.

Wheat prices 1806–75 are Florence wheat prices from P. Bandettini, 'I prezzi sul mercato di Firenze dal 1800 al 1890', *Archivio Economico dell'Unificazione Italiana*, **5**, 1 (1957), p. 13.

Austria (Cisleithania) 1820–75

Crude birth, marriage and death rates are from Mitchell, *ibid.*, pp. 115, 118. The year ends October 31 from 1820–55.

Infant mortality rate 1820–9 is estimated to be 251, which is the average infant mortality rate 1830–9 from Mitchell, *ibid.*, p. 137. Mitchell shows infant mortality for Austria 1806–29, but the figures appear to be improbably low. Infant mortality rate 1830–75 is from Mitchell, *ibid.*, pp. 137, 138. The year ends October 31 from 1820–55.

Rye prices 1816–75 are Vienna korn (rye) prices from A. F. Pribram, *Materialien zur Geschichte der Preise und Löhne in Österreich* (Wien: Ueberreuters, 1938), vol. 1, pp. 393–394. The year ends October 31 from 1820–55.

France rural 1670–1739

Births, marriages, and deaths of individuals aged five years and older are from D. Rebaudo, 'Le mouvement annuel de la population française rurale de 1670 à 1740', *Population*, **34**, 3 (1979), pp. 594–596.

Wheat prices 1666–1739 are the average of the following detrended wheat price series: Aix, Angers, Douai, Grenoble, Paris, Poitiers, Pontoise, St. Etienne, Strasbourg, and Toulouse. Aix prices are from R. Baehrel, *Une Croissance: La Basse-Provence Rurale (Fin XVI^e Siècle-1789)* (Paris: SEVPEN, 1961), p. 535. Angers prices are from H. Hauser, *Recherches et Documents sur l'Histoire des Prix en France de 1500 à 1800* (Paris: Les Presses Modernes, 1936), pp. 259–261. Douai prices are from M. Mestayer, 'Prix du blé et de l'avoine de 1329 à 1793', *Revue du Nord*, **45**, 178 (1963), pp. 169–170. Grenoble prices are from Hauser, *ibid.*, pp. 368–369. Paris prices are from M. Baulant, 'Le prix des grains à Paris de 1431 à 1788', *Annales Economies Sociétés Civilisations*, **23**, 3 (1968), pp. 539–540. Poitiers prices are from P. Raveau, 'Essai sur la situation économique et l'état social en Poitou au 16e siècle', *Revue d'Histoire Économique et Sociale*, **18** (1930), pp. 315–365. Pontoise prices are from J. Dupâquier, M. Lachiver, and J. Meuvret, *Mercuriales du Pays de France et du Vexin Français (1640–1792)* (Paris: SEVPEN, 1968), pp. 31–101. St. Etienne prices are from L.-J. Gras, *Histoire du Commerce Local et des Industries qui s'y Rattachent dans la Région Stéphanoise et Forézienne* (Saint-Etienne: Theolier, 1910), pp. 269–285. Strasbourg prices are from A. Hanauer, *Études Économiques sur l'Alsace Ancienne et Moderne* (Paris: Durand et Pédone-Lauriel, 1878), vol. 2, pp. 97–98. Toulouse prices are from G. and G. Frêche, *Les Prix des Grain, des Vins et des Légumes à Toulouse (1486–1868)* (Paris: Presses Universitaires de France, 1967), pp. 88–89.

Minden–Kleve 1688–1756

This includes the regions of Minden, Kleve, Ravensberg, and Mark. Births, marriages, and deaths 1688–1756 for Minden and Ravensberg are from J. P. Süssmilch, *Die Göttliche Ordnung in den Veränderungen des Menschlichen Geschlechts, aus der Geburt, dem Tode und der Fortpflanzung desselben* (Berlin, 1775), vol. 1, pp. 116–119. Births, marriages, and deaths 1688–97 for Kleve and Mark are from Behre, *ibid.*, p. 451. Births, marriages, and deaths 1698–1756 for Kleve and Mark are from Süssmilch, *ibid.*, vol. 1, pp. 120–122. Deaths probably include stillbirths which should be removed. This is done by multiplying the number of births in a given year by 0.039, the estimated stillbirth rate in Prussia 1816–70 from Königliches Statistisches Bureau, *ibid.*, **188** (1904), pp. 12–13, and subtracting this result from deaths.

Infant mortality rate 1688–1756 is estimated to be 188 which was the average rate in Prussia 1816–70 from Königliches Statistisches Bureau, *ibid.*, **48** (1879), p. 97, and *ibid.*, **188** (1904), p. 121.

Rye prices 1684–1756 are Ravensberg rye prices from W. Naudé, *Die Getreidehandelspolitik und Kriegsmagazinverwaltung Brandenburg–Preussens bis 1740* (Berlin: Parey, 1901), vol. 2, pp. 536–538 and Naudé and Stalweit, *ibid.*, pp. 602–604.

Central Prussia 1689–1760

Births, marriages, and deaths 1689–1760 are from Behre, *ibid.*, pp. 445–449. The series are 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 neighbouring region. Deaths probably include stillbirths which should be removed. This is done by multiplying the number of births in a given year by 0.039, the estimated stillbirth rate in Prussia 1816–70 from Königliches Statistisches Bureau, *ibid.*, **188** (1904), pp. 12–13, and subtracting this result from deaths.

Infant mortality rate 1689–1760 is estimated to be 188 which was the average rate in Prussia 1816–70 from Königliches Statistisches Bureau, *ibid.*, **48** (1879), p. 97, and *ibid.*, **188** (1904), p. 121.

Rye prices 1685–1760 are Berlin rye prices. The Berlin rye prices are from Dieterici, *ibid.*, pp. 90–92 with gaps filled using Berlin rye prices from Naudé, *ibid.*, p. 572, Naudé and Stalweit, *ibid.*, pp. 624–631, and Stalweit, *ibid.*, pp. 647–651.

Appendix Table 1. *Regressions of fertility, nuptiality, and mortality rates on grain prices*

Place	Eq.	Dependent variable	Period	Obs.	Constant	Grain prices			
						Lag 0	Lag 1	Lag 2	Lag 3
England	1	CBR	1756–1870	115	1.081 a	−0.069 a	−0.028 c	0.018	−0.009
Netherlands	1	CBR	1811–1870	60	1.164 a	−0.059 b	−0.076 a	−0.028	0.024
Belgium	1	CBR	1811–1870	60	1.130 a	−0.062 a	−0.078 a	0.020	−0.020
France	1	CBR	1756–1870	115	1.079 a	−0.040 a	−0.079 a	0.052 a	−0.016
Prussia	1	CBR	1756–1870	115	1.068 a	−0.035 c	−0.109 a	0.050 b	0.016
Denmark	1	CBR	1756–1870	115	1.054 a	−0.017	−0.066 a	0.026 d	−0.002
Sweden	1	CBR	1756–1870	115	1.086 a	−0.025	−0.142 a	0.003	0.059 c
Tuscany	1	CBR	1817–1870	54	1.183 a	−0.080 d	−0.174 a	0.043	0.035
Austria	1	CBR	1827–1870	44	1.149 a	−0.043 d	−0.164 a	0.081 a	−0.028
England	1	CBR	1675–1755	81	1.152 a	−0.096 a	−0.071 a	0.019	−0.011
France Rural	1	Births	1677–1734	58	1.193 a	−0.048 d	−0.204 a	0.093 b	−0.049 d
Minden–Kleve	1	Births	1695–1751	57	1.176 a	−0.049 c	−0.116 a	0.033 d	−0.001
Central Prussia	1	Births	1696–1755	60	1.204 a	0.017	−0.169 a	0.014	−0.017
England	1	CBR	1546–1674	129	1.176 a	−0.074 a	−0.121 a	0.054 a	−0.064 a
England	2	CBR	1756–1870	115	1.193 a	−0.068 a	−0.039 a	0.022 d	−0.018
Netherlands	2	CBR	1815–1870	56	1.208 a	−0.046 c	−0.092 a	0.006	0.041 d
Belgium	2	CBR	1815–1870	56	1.155 a	−0.047 b	−0.108 a	0.057 b	−0.032 d
France	2	CBR	1756–1870	115	0.992 a	−0.036 a	−0.083 a	0.062 a	−0.020 d
Prussia	2	CBR	1759–1870	112	1.102 a	−0.032 c	−0.084 a	0.050 b	0.005
Denmark	2	CBR	1756–1870	115	1.083 a	−0.009	−0.065 a	0.024 d	−0.005
Sweden	2	CBR	1756–1870	115	1.221 a	−0.004	−0.092 a	0.016	0.028
Tuscany	2	CBR	1821–1870	50	1.138 a	−0.065	−0.088 d	0.078	−0.025
Austria	2	CBR	1831–1870	40	1.122 a	−0.035	−0.098 a	0.094 a	−0.022
England	2	CBR	1675–1755	81	1.216 a	−0.079 a	−0.035 c	0.050 a	−0.009
France Rural	2	Births	1681–1734	54	1.303 a	−0.010	−0.150 a	0.029	−0.033
Minden–Kleve	2	Births	1699–1751	53	1.293 a	−0.050 c	−0.104 a	0.064 b	0.052 c
Central Prussia	2	Births	1700–1755	56	1.203 a	0.043	−0.150 a	0.004	−0.022
England	2	CBR	1550–1674	125	1.324 a	−0.100 a	−0.088 a	0.065 a	−0.041 b
England	3	CMR	1756–1870	115	1.124 a	−0.145 a	−0.046 c	0.065 b	−0.023
Netherlands	3	CMR	1815–1870	56	1.126 a	−0.133 a	−0.105 a	−0.063 d	0.027
Belgium	3	CMR	1815–1870	56	1.061 a	−0.118 a	−0.113 b	0.026	0.031
France	3	CMR	1756–1870	115	0.799 a	−0.305 a	0.178 b	−0.144 c	−0.050
Prussia	3	CMR	1759–1870	112	0.738 a	−0.043	0.035	0.014	0.011
Denmark	3	CMR	1782–1870	89	0.742 a	−0.057	−0.039	−0.024	0.000
Sweden	3	CMR	1756–1870	115	1.016 a	−0.092 b	−0.186 a	0.046	−0.026
Tuscany	3	CMR	1821–1870	50	0.920 a	−0.387 b	0.133	0.124	−0.070
Austria	3	CMR	1831–1870	40	0.897 a	−0.075	0.112 d	−0.004	0.030
England	3	CMR	1675–1755	81	0.652 a	−0.072 b	0.037	0.063 b	0.022
France Rural	3	Marriages	1681–1734	54	0.796 a	−0.238 a	−0.134 d	0.068	0.121 d
Minden–Kleve	3	Marriages	1699–1751	53	0.874 a	−0.123 a	−0.041	0.063 c	0.033
Central Prussia	3	Marriages	1700–1755	56	0.986 a	−0.183 a	−0.021	−0.072 c	0.018
England	3	CMR	1550–1674	125	1.076 a	−0.200 a	−0.034	−0.051	0.009
England	4	NIDR	1756–1870	115	1.087 a	0.052 d	−0.075 c	0.080 b	−0.087 b
Netherlands	4	NIDR	1811–1870	60	0.775 a	0.081	−0.017	0.205 a	−0.043
Belgium	4	NIDR	1811–1870	60	0.799 a	0.086 d	−0.060	0.157 b	0.044
France	4	NIDR	1756–1870	115	0.785 a	0.084	−0.080 d	0.293 a	−0.079
Prussia	4	NIDR	1756–1870	115	0.813 a	0.077	0.243 a	−0.077	−0.003
Denmark	4	NIDR	1756–1870	115	0.925 a	0.086	0.019	0.009	−0.060
Sweden	4	NIDR	1756–1870	115	0.724 a	0.159 d	0.232 b	0.115	−0.122
Tuscany	4	NIDR	1817–1870	54	0.096	0.417 d	0.339	0.568 c	−0.542 c
Austria	4	NIDR	1827–1870	44	0.017	0.439 a	0.222 d	0.064	0.196 d
England	4	NIDR	1675–1755	81	0.621 a	0.113 c	0.191 a	0.097 c	−0.019
France Rural	4	NI. Deaths	1677–1734	58	0.856 a	0.298 a	0.285 b	−0.210 c	0.019
Minden–Kleve	4	NI. Deaths	1695–1751	57	0.287 d	0.115	0.190 c	0.057	0.354 a
Central Prussia	4	NI. Deaths	1696–1755	60	0.644 a	0.105	0.193 b	−0.026	0.017
England	4	NIDR	1546–1674	129	0.891 a	0.065	0.094 d	0.105 d	0.008
England	5	CDR	1756–1870	115	1.094 a	0.021	−0.067 b	0.062 b	−0.066 b
Netherlands	5	CDR	1811–1870	60	0.852 a	0.060	−0.028	0.140 b	−0.023
Belgium	5	CDR	1811–1870	60	0.867 a	0.058	−0.069	0.128 b	0.038
France	5	CDR	1756–1870	115	0.833 a	0.057	−0.084 c	0.251 a	−0.057
Prussia	5	CDR	1756–1870	115	0.887 a	0.046	0.173 a	−0.058	0.003
Denmark	5	CDR	1756–1870	115	0.945 a	0.068	−0.003	0.019	−0.050
Sweden	5	CDR	1756–1870	115	0.796 a	0.167 c	0.138 d	0.086	−0.091
Tuscany	5	CDR	1817–1870	54	0.434 c	0.254 d	0.210	0.414 b	−0.399 c
Austria	5	CDR	1827–1870	44	0.302 d	0.328 a	0.101	0.077	0.139 d
England	5	CDR	1675–1755	81	0.705 a	0.073 d	0.140 a	0.086 c	−0.008
France Rural		N.A.							
Minden–Kleve	5	Deaths	1695–1751	57	0.490 a	0.077	0.119 d	0.060	0.263 a
Central Prussia	5	Deaths	1696–1755	60	0.784 a	0.079	0.095 d	−0.005	0.006
England	5	CDR	1546–1674	129	0.970 a	0.027	0.049	0.095 c	−0.010

Notes: The secular trend has been removed from each series by dividing each data point, x, in a series by an eleven y
and corrected R-squared are calculated for the untransformed variables.

The significance level of the test statistics is: a 1%, b 5%, c 10%, d 20%.

* Non-infant deaths are used in place of non-infant death rates in France Rural, Minden-Kleve, and Central P

Lag 3	Lag 4	Non-infant death rate* Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	R-Sq.	Corr. R-Sq.	Durbin Watson
-0.009	0.006	—	—	—	—	—	0.38	0.36	1.99
0.024	−0.025	—	—	—	—	—	0.42	0.37	1.99
-0.020	0.010	—	—	—	—	—	0.49	0.45	1.99
-0.016	0.004	—	—	—	—	—	0.42	0.40	1.91
0.016	0.008	—	—	—	—	—	0.45	0.43	2.01
-0.002	0.004	—	—	—	—	—	0.20	0.18	2.03
0.059 c	0.018	—	—	—	—	—	0.41	0.38	2.02
0.035	−0.007	—	—	—	—	—	0.49	0.45	1.90
-0.028	0.004	—	—	—	—	—	0.64	0.60	2.21
-0.011	0.007	—	—	—	—	—	0.39	0.35	2.06
-0.049 d	0.012	—	—	—	—	—	0.60	0.57	1.98
-0.001	−0.041 d	—	—	—	—	—	0.38	0.34	1.82
-0.017	−0.046 c	—	—	—	—	—	0.53	0.50	1.83
-0.064 a	0.029 d	—	—	—	—	—	0.35	0.32	2.07
-0.018	−0.004	−0.108 a	−0.013	0.064 c	0.016	−0.045 d	0.47	0.42	1.97
0.041 d	−0.058 b	−0.080 c	−0.109 a	0.118 a	−0.022	0.035	0.63	0.55	1.82
-0.032 d	−0.007	−0.122 a	0.033	0.086 b	−0.002	−0.011	0.68	0.61	1.69
-0.020 d	−0.007	−0.021	0.016	0.055 b	0.006	0.037 c	0.52	0.48	1.93
0.005	0.008	−0.045 d	−0.048 c	0.047 d	−0.011	0.008	0.52	0.47	1.97
-0.005	0.002	−0.066 b	0.001	0.006	0.005	0.023	0.29	0.23	2.03
0.028	0.015	−0.156 a	−0.017	0.024	−0.010	−0.027	0.59	0.56	2.02
-0.025	0.027	−0.050 c	−0.001	−0.002	−0.030	0.019	0.54	0.43	2.07
-0.022	0.005	−0.084 b	−0.064 b	0.030	0.016	0.035	0.81	0.75	1.98
-0.009	−0.006	−0.114 a	−0.107 a	0.042	0.021	0.020	0.67	0.63	1.97
-0.033	−0.008	−0.126 a	−0.014	0.066 d	−0.052	−0.009	0.71	0.65	1.96
0.052 c	−0.008	−0.073 b	−0.072 c	−0.083 b	−0.010	−0.011	0.50	0.40	1.86
-0.022	−0.025	−0.105 b	0.037	0.006	0.023	−0.011	0.60	0.53	1.82
-0.041 b	−0.001	−0.115 a	−0.083 a	0.045 b	−0.044 c	0.039 d	0.58	0.54	2.06
-0.023	0.004	−0.137 c	0.154 b	0.122 c	−0.073	−0.045	0.43	0.38	2.07
0.027	0.036	−0.080	0.110 d	0.063	0.012	0.005	0.54	0.45	2.11
0.031	0.006	−0.142 c	0.149 b	0.182 b	0.063	−0.147 c	0.72	0.66	1.86
-0.050	−0.025	0.177 c	0.202 c	0.012	0.081	0.072	0.22	0.16	1.92
0.011	−0.050 d	−0.081 d	0.195 a	0.076	0.143 b	−0.043	0.25	0.18	2.01
0.000	−0.006	−0.002	0.131 c	0.059	0.049	0.145 b	0.20	0.11	2.04
-0.026	0.032	−0.023	0.061 d	0.101 a	0.069 c	0.000	0.50	0.46	2.04
-0.070	0.176	−0.031	0.094	0.026	0.011	−0.002	0.41	0.27	2.01
0.030	−0.066	−0.263 a	0.179 b	0.004	0.178 b	0.007	0.67	0.58	1.94
0.022	0.024	−0.140 b	0.125 b	0.203 a	−0.014	0.098 c	0.54	0.48	2.03
0.121 d	0.154 c	−0.002	0.292 a	0.170 d	−0.185 b	−0.040	0.55	0.46	1.96
0.033	−0.079 b	0.022	0.174 a	0.048	−0.005	0.032	0.51	0.40	1.79
0.018	−0.076 b	0.029	0.179 a	0.058	0.099 c	−0.013	0.50	0.41	2.12
0.009	−0.082 c	−0.089 d	0.147 a	0.118 b	0.032	0.073 d	0.36	0.31	2.04
-0.087 b	−0.056 d	—	—	—	—	—	0.14	0.11	2.10
-0.043	−0.002	—	—	—	—	—	0.18	0.12	2.05
0.044	−0.027	—	—	—	—	—	0.18	0.12	2.04
-0.079	−0.003	—	—	—	—	—	0.15	0.12	2.12
-0.003	−0.053	—	—	—	—	—	0.30	0.28	2.10
-0.060	0.021	—	—	—	—	—	0.04	0.01	2.09
-0.122	−0.107	—	—	—	—	—	0.26	0.23	2.06
-0.542 c	0.123	—	—	—	—	—	0.42	0.37	1.92
0.196 d	0.066	—	—	—	—	—	0.39	0.32	2.06
-0.019	−0.001	—	—	—	—	—	0.24	0.21	2.16
0.019	−0.253 b	—	—	—	—	—	0.46	0.42	1.61
0.354 a	−0.004	—	—	—	—	—	0.33	0.28	2.00
0.017	0.053	—	—	—	—	—	0.21	0.15	2.00
0.008	−0.165 b	—	—	—	—	—	0.15	0.12	2.12
-0.066 b	−0.044 d	—	—	—	—	—	0.11	0.08	2.10
-0.023	−0.003	—	—	—	—	—	0.13	0.07	2.03
0.038	−0.023	—	—	—	—	—	0.15	0.09	2.05
-0.057	0.000	—	—	—	—	—	0.17	0.14	2.09
0.003	−0.049	—	—	—	—	—	0.26	0.23	2.09
-0.050	0.023	—	—	—	—	—	0.04	0.00	2.09
-0.091	−0.095	—	—	—	—	—	0.23	0.21	2.06
-0.399 c	0.089	—	—	—	—	—	0.40	0.35	1.92
0.139 d	0.054	—	—	—	—	—	0.35	0.29	2.04
-0.008	0.005	—	—	—	—	—	0.23	0.19	2.14
0.263 a	−0.010	—	—	—	—	—	0.31	0.26	1.96
0.006	0.032	—	—	—	—	—	0.15	0.09	2.02
-0.010	−0.132 b	—	—	—	—	—	0.13	0.11	2.09

ı eleven year average of data points centred around x. The regressions are corrected for second order autoregressive disturbance:

:entral Prussia.

Corr. R-Sq.	Durbin Watson	F	Lag Sum (Lag 0 to Lag 4) Grain prices	Lag Sum (Lag 0 to Lag 4) Non-infant death rate	χ^2 (Lag 0 to Lag 4) Grain prices	χ^2 (Lag 0 to Lag 4) Non-infant death rate
0.36	1.99	10.98 a	−0.082 b	—	54.53 a	
0.37	1.99	5.36 a	−0.163 a	—	34.28 a	
0.45	1.99	7.43 a	−0.130 a	—	43.49 a	
0.40	1.91	12.17 a	−0.079 a	—	85.69 a	
0.43	2.01	14.51 a	−0.070 b	—	77.24 a	
0.18	2.03	5.83 a	−0.055 d	—	24.12 a	
0.38	2.02	13.30 a	−0.087	—	48.98 a	
0.45	1.90	6.25 a	−0.182 c	—	31.59 a	
0.60	2.21	12.20 a	−0.150 b	—	55.02 a	
0.35	2.06	11.72 a	−0.152 a	—	41.86 a	
0.57	1.98	11.34 a	−0.195 a	—	85.39 a	
0.34	1.82	5.59 a	−0.174 a	—	23.12 a	
0.50	1.83	8.81 a	−0.202 a	—	48.42 a	
0.32	2.07	15.09 a	−0.177 a	—	74.58 a	
0.42	1.97	8.75 a	−0.108 a	−0.085	58.53 a	18.34 a
0.55	1.82	6.21 a	−0.149 a	−0.059	35.04 a	22.23 a
0.61	1.69	7.57 a	−0.138 a	−0.016	54.65 a	14.16 b
0.48	1.93	9.73 a	−0.084 a	0.092 b	91.42 a	20.51 a
0.47	1.97	9.96 a	−0.052 d	−0.050	39.38 a	10.06 c
0.23	2.03	4.43 a	−0.052 d	−0.031	19.48 a	10.41 c
0.56	2.02	14.20 a	−0.036	−0.186 a	17.27 a	42.48 a
0.43	2.07	3.66 a	−0.073	−0.064	14.91 b	5.92
0.75	1.98	9.75 a	−0.056	−0.067	23.40 a	20.27 a
0.63	1.97	12.57 a	−0.079 b	−0.137 b	40.96 a	42.35 a
0.65	1.96	8.82 a	−0.171 a	−0.135 b	29.66 a	12.57 b
0.40	1.86	4.64 a	−0.047	−0.249 a	28.73 a	10.24 c
0.53	1.82	5.79 a	−0.149 a	−0.051	31.62 a	6.60
0.54	2.06	14.54 a	−0.166 a	−0.159 a	66.57 a	47.68 a
0.38	2.07	8.62 a	−0.145 b	0.021	47.76 a	13.18 b
0.45	2.11	12.47 a	−0.238 b	0.110	18.48 a	9.62 c
0.66	1.86	8.80 a	−0.167 b	0.105	60.99 a	20.58 a
0.16	1.92	3.22 a	−0.346 a	0.545 a	23.68 a	14.14 b
0.18	2.01	10.56 a	−0.032	0.291	4.21	29.78 a
0.11	2.04	1.99 b	−0.126 d	0.382 b	5.62	9.91 c
0.46	2.04	13.83 a	−0.226 b	0.208 b	35.53 a	11.77 b
0.27	2.01	2.23 b	−0.024	0.098	11.97 b	1.41
0.58	1.94	5.58 a	−0.003	0.105	5.65	35.69 a
0.48	2.03	8.89 a	0.074	0.273 b	12.27 b	25.78 a
0.46	1.96	7.06 a	−0.030	0.235 d	23.58 a	16.32 a
0.40	1.79	4.65 a	−0.147 d	0.271 b	18.13 a	16.03 a
0.41	2.12	6.81 a	−0.334 a	0.352 b	19.71 a	11.72 b
0.31	2.04	6.38 a	−0.359 a	0.281 b	23.65 a	18.29 a
0.11	2.10	3.79 a	−0.086	—	17.18 a	
0.12	2.05	1.99 c	0.224 d	—	10.60 c	
0.12	2.04	1.69 d	0.200 c	—	10.74 c	
0.12	2.12	7.93 a	0.214 d	—	24.48 a	
0.28	2.10	8.52 a	0.188 c	—	32.90 a	
0.01	2.09	2.45 b	0.076	—	3.90	
0.23	2.06	6.86 a	0.277	—	27.63 a	
0.37	1.92	5.52 a	0.905 a	—	42.26 a	
0.32	2.06	3.89 a	0.986 a	—	20.43 a	
0.21	2.16	9.36 a	0.380 b	—	14.98 b	
0.42	1.61	7.18 a	0.139	—	39.46 a	
0.28	2.00	3.95 a	0.712 a	—	29.53 a	
0.15	2.00	4.00 a	0.343 c	—	7.27	
0.12	2.12	6.59 a	0.107	—	11.25 b	
0.08	2.10	3.53 a	−0.094	—	14.90 b	
0.07	2.03	1.32	0.147 d	—	7.36	
0.09	2.05	1.48	0.131 d	—	8.68 d	
0.14	2.09	6.33 a	0.167 d	—	25.20 a	
0.23	2.09	7.23 a	0.114 d	—	26.85 a	
0.00	2.09	2.21 c	0.056	—	3.72	
0.21	2.06	5.97 a	0.205	—	26.06 a	
0.35	1.92	5.14 a	0.567 b	—	38.67 a	
0.29	2.04	3.38 a	0.699 a	—	18.63 a	
0.19	2.14	8.27 a	0.296 b	—	13.66 b	
0.26	1.96	3.75 a	0.510 a	—	28.67 a	
0.09	2.02	3.57 a	0.207 d	—	4.39	
0.11	2.09	5.54 a	0.028	—	11.24 b	

utoregressive disturbances using the iterative Cochrane–Orcutt procedure. R-squared