On the issue of causes of mortality crises: The use of matching and inverse probability weighting to analyze mortality in 18th to 19th century southern Sweden[1]

Tommy Bengtsson[2] and Göran Broström[3]

Abstract

From studies at macro level, we know that environmental conditions, such as food prices and temperature had a strong impact both on fertility and mortality in the past. From micro studies, we know that the parents were of outmost importance to the health of their children, since extra-familial resources were few and inadequate. We also know that mortality in some years was simply far higher than in other years, and that such crises years sometimes succeeded each other. The role of each of these factors is, however, somewhat unclear since they might not only influence mortality *directly*, but also *indirectly*. And they might influence mortality during crises years differently from other years.

In the analyses, we use mainly two (non-standard) approaches, first a *proportional hazards model* with the extra twist of a *counter-matching nested case-control design*. The purpose of the counter-matching is two-fold; a balanced composition with respect to certain covariates in each risk set is achieved, and the risk set sizes are drastically reduced, thus easing the computational burden. The second approach is the *additive hazards model*, in combination with *dynamic path analysis*. The additive model allows for investigating the mediating effect of intermediate covariates in a causal framework. The statistical analyses are performed in the R statistical computing environment, especially with the aid of the package eha. The individual level data comes from the Scanian Demographic Database and covers five rural parishes for the period 1766 to 1895. While the data on food prices refers to the local area of these parishes, the data on temperature refers to a closely situated town.

We generally find that the *direct* effects are dominating. The direct effects of winter temperatures are far stronger that the indirect effects, via food prices. The direct effects of food prices are far stronger than the indirect effects, via parental deaths. We also find that the causal mechanisms during crisis years are quite different from other years, and not only in scale. While food prices are much more important than temperature in crisis years, it is the other way around in other years. The impact of parental deaths also differs, but here it is more a question of magnitude. Mothers become much more important during crisis years.

1 Paper presented in Session 201: A historical demography of epidemics, XXVI IUSSP International Population Conference, Marrakesh, 27 September – 2 October 2009.
2 Centre for Economic Demography and Department of Economic History, Lund University
3 Centre for Population Studies (ALC) and Department of Statistics, Umeå University

Introduction

Analyses of variations of mortality have basically followed two paths. The first one takes a time series approach, analyzing causes of variation in mortality over a certain period of time (Lee 1981). In this approach non-linear effects of such external factors as real wages, food prices, temperature, etc are analyzed. The focus is thus on testing *hypotheses* of causes of mortality fluctuations. The other path takes an entirely different approach, sampling on one or a few mortality crises, this way taking an *explorative* approach.

Real wages and food prices often have a strong time trend as well as a fair amount of fluctuations around this trend. Due to the time periods analyzed, often less than 100 years, the trend itself (by definition) contains little information and since other factors, such as urbanization, expansion of schooling and health care, show similar trends, it is difficult to establish causality. The focus has therefore been on the effects of the fluctuations of the external factors, both in analyses of mortality at macro and micro level. This has been proven very useful since it provides a basis to establish causality, the reason being that there is a lot of variation in the explanatory variable after the trend has been removed.

Numerous studies using the time series approach, based on annual aggregated data from preindustrial populations, show that fluctuations in food prices affect demographic outcomes, particularly fertility, but also mortality and migration (Bengtsson 1993a; Galloway 1988; Lee 1981). The results refer not only to preindustrial Europe but also other parts of the world as well as for later periods (Lee 1990; for an overview, see Bengtsson & Reher 1998). Most of these studies are based on total number of events for the entire population of a certain area, often a country. From an analysis of age-specific mortality for Sweden, we know, however, that it was in particular children in ages five years and above and adults that were vulnerable to short-term economic stress (Bengtsson & Ohlsson 1985:317). The mortality among infants seems to follow its own rhythm (Bengtsson & Ohlsson 1985:317; Utterström 1957). Not only fluctuations in food prices influence demographic events; cold winters and warm summers affect demographic outcomes too (Lee 1981; Richards 1984; Tromp 1963). Most of the studies are based on estimations of distributed lag models with up to five years delay (for other methods, see Bengtsson & Broström 1997). Special attention has, however, been taken to the demographic response to extraordinary situations by analyzing non-linearity and runs (for example, see Lee 1981). Response patterns of aggregated data may, however, conceal great intra-societal diversity in patterns of demographic responses, not only regarding age, as demonstrated by Bengtsson and Ohlsson (1985), but also with respect to other factors, such as socio-economic status and sex.

Advances in data and methods allow for more detailed examination and comparison of demographic responses to economic and environmental pressure. Application of combined event history and time series techniques to longitudinal, individual and household level data allows for identifying demographic responses to changing economic conditions by individual socio-economic and demographic characteristics (Bengtsson 1993b), as well as by household characteristics (Bengtsson, Campbell, Lee et al. 2004). Such analyses show that patterns of demographic responses by socio-economic status, household composition, and individual characteristics to economic fluctuations were diverse (Allen, Bengtsson, & Dribe 2005; Bengtsson, Campbell, Lee et al. 2004; Bengtsson & Saito 2000). This approach also allows for analyses of extreme environmental situations by investigating non-linearity (Bengtsson 2000). Still, previously it has not been used to study whether mortality crises are particular in terms of their causes or just “more of the same”.

One problem is that the time series approach, whether applied to aggregated or individual level data, does not provide the answers to whether mortality crises fundamentally differ from less pronounced peaks in mortality in terms of their causes. This problem was addressed in a recent paper by Bengtsson and Broström (2009), who found that the effects of food prices on mortality during crisis years, defined as succeeding years of extra-high mortality, differed from other years of high mortality. Potential effect of other external factors, such as temperature, was also addressed. The finding was that while food prices affected all age-groups (but infants), temperature and production affected only adults.

Another problem is that external factors might influence each other. Temperature may, for example, not only have an effect on mortality but also on harvest outcomes and food prices, which potentially creates biased estimates of both the effect of temperature and food prices on mortality. This problem is illustrated in Figure 1, in which X(t) is temperature, Y(t) is food prices, and *d*N(t) is the differential of the counting process, which is child mortality. To be able to estimate the effects of temperature on child mortality, we also have to consider the influence of temperature on food prices.

- Figure 1

Yet another problem in observational studies is that the interaction between factors at macro and micro level is not well understood. We know, for example, that mortality for infants and children increases after the loss of a parent. This effect is stronger for infants and stronger if it is the mother who is lost. We also know that the mortality of both children and parents are affected by external factors, such as food prices. In years of excess mortality, the effects of prices on children might then run two ways; *direct effects* of food shortage and *indirect effects* of losing a parent during times of food shortage. In such cases, it is necessary to use methods that avoid the bias that will result from traditional methods based on conditioning. Again, we can use Figure 1 to illustrate the problem. Now X(t) is food prices, Y(t) is parental deaths, and *d*N(t) is the differential of the counting process, which again is child mortality and the be able to address the problem of causality, we have to consider the influence of food prices on parental deaths.

In order to approach these problems, this paper expands into the area of causal inference and inverse probability weighting (see Hernan, Lanoy, Costagliola, & Robins 2006), and references therein) as well as nested case-control matching (see Langholtz & Borgan 1995). We will investigate whether this approach will solve both the problem of identifying the causes of mortality crises and the problem of confounding.
The application of matching and inverse probability weighting in Cox regression requires software that can handle time-varying weights. No standard software can do that (to our knowledge), so it has been implemented into the R package eha (Broström 2009).

Context and Data

Longitudinal demographic data on individuals and household socio-economic data have been combined with community data on food prices and temperature. The individual level data comes from the Scanian Demographic Database, which covers nine rural parishes and one town situated in Scania in the southernmost part of Sweden. Five of the rural parishes are included in this study: Hög, Kävlinge, Halmstad, Sireköpinge, and Kågeröd. The material for two of the parishes dates back to 1646 and for the others to the 1680s. While the publicly available records end in 1895, we end in 1860 when industrial activities evolved in this part of the country. Our interest in socio-economic position further limits our dataset since the data for the 18th century shows some gaps, which is why we chose 1766 as the starting year.

The parish register material is of high quality and shows no gaps for births, deaths, or marriages. Migration records are less plentiful but a continuous series exists from the latter part of the eighteenth century. Information concerning farm size and property rights, in addition to various sorts of information from poll-tax records, land registers, and household examination records, are linked to family reconstitutions based on the parish records of marriages, births, and deaths. Taken together, we have very rich information on the household size and structure as well as socio-economic conditions. In addition, we have good information on food prices and temperature. Data on food prices is available for the local area and refers to the fall. We are using the price of rye, since this was the most common grain in this part of the country. Data on temperature comes from Lund, apart from 1821 to 1833, for which we have used data for Copenhagen instead.

The selected parishes are compact in their geographical location, showing the variations that could occur in peasant society with regard to size, topography, and socioeconomic conditions, and they offer good source material. Life expectancy at birth follows the same development as the entire country, but is about one year higher (Bengtsson & Dribe 1997; Bengtsson 2004). The entire area was open farmland, except for northern Halmstad and parts of Kågeröd, which were more wooded. Halmstad, Sireköpinge, and

Kågeröd were predominantly noble parishes, while freehold and crown land dominated in Kävlinge and Hög. The parishes each had between 400 and 1,700 inhabitants in the latter half of the nineteenth century. The agricultural sector in Sweden, and Scania, became increasingly commercialized during the early nineteenth century. New crops and techniques were introduced. Enclosure reforms and other reforms in the agricultural sector influenced population growth, particularly in Sireköpinge, which experienced fast population growth. In Kävlinge, the establishment of several factories and railroad communications led to rapid expansion from the 1870s onwards.

Land was the most important source of wealth in these societies. The social structure of the agricultural sector is often difficult to analyze since differences in wealth between various categories of farmers and occupations are unclear and subject to change with the passage of time. Data from land registers on different types of tenure must be combined with information from poll-tax records concerning farm size in order to arrive at a better understanding of each household's access to land. Here we only differentiate between two social groups; (1) the landed, which includes freeholder and tenants on noble land with farms large enough to support a family, and (2) landless, which not only include landless day-labourers and artisans but also peasants with small plots of land, so small that they would have to work outside their farm to be able to support their families. The dividing line between peasants who can and cannot support a family on their land is set to 1/16 *mantal* based on well-founded arguments from numerous studies in this field of research, stating that peasants with smaller farms were not self-supporting (for an overview, see Bengtsson 2004; Bengtsson & Dribe 2005).

The nineteenth century was a period of considerable social change in the countryside. It has been described as a period of proletarization and pauperization. The share of landless increased (Carlsson 1968). Downward mobility was significant since many children of farmers were unable to obtain a farm themselves. This was true both for Sweden in general and for the area we study (Lundh 1998). Not only did the share of the landless strata increase but their economic situation worsened as well. They became, for example, more vulnerable to short-term economic stress than before, as shown by their mortality and fertility responses to food prices (Bengtsson 2000, 2004; Bengtsson & Dribe 2005). What actions where then taken to reduce the negative impact of high food prices?

The Swedish poor relief system involved the state, the county administration, the local community and church, the employer and the family (Skoglund 1992; Åmark 1915). As stated by laws from the 1760s, local communities were obliged to take care of very poor people that were permanently sick or handicapped, or elderly without relatives or former employers to take care of them. On average, only a small fraction (2.1 percent), of the population received parish relief as shown by a public investigation in 1829 (Skoglund 1992); the figure for Malmöhus County, in which the five parishes in this study are located, was even lower (1.4 percent). The poor relief system at the beginning of the nineteenth century was obviously not designed to take care of large groups of people in temporary need during years of high food prices. Furthermore, the granary system, which was abolished in 1823, was intended to provide loans to producers, not consumers (Olofsson 1996:26). Social tensions grew and efforts were made by the state to create work in years of bad harvests. Finally, a new poor law system was introduced in 1847 (Skoglund 1992; Banggaard 2002) after which individuals and families could receive some temporary assistance. Before that time, while the poor temporarily might be granted a tax exemption, they were not given any direct support (for more details on the area we study, see Banggaard 2002; Bengtsson 2004).

Thus most families in the area we study had to rely on themselves when conditions worsened. While farmers with land were able to obtain loans, the situation for the landless was bleak. An alternative was to get help from networks of kin and others, generally available to the families that had been residing for generations in the same parish. Inmigrants, consequently, had smaller social networks. Outmigration was not really an option to anyone as conditions were similar throughout this part of the country (Dribe 2000) due to the limited size of the industrial sector and the low degree of urbanization.

Famines, Weather, and Mortality Crises

Various methods have been suggested for identifying mortality crises (for example, see Dupâquier 1989). Here we have simply selected pairs of succeeding years in which the number of deaths was at least 25 percent above the average since the previous crises, and most often much more. This occurs five times in the period 1766 to 1860 in the five rural parishes in Scania included in this study, namely in 1772/3, 1785/6, 1831/2, 1846/7, and 1852/3 (Figure 1). In detecting the first crisis years we used data back to 1750.

- Figure 2 here

While the infant mortality during the five crises was only 23 percent above the average, the mortality in ages 1-15 year was 73 percent, in ages 25-55 years 78 percent and in ages 55+ years 99 percent above the average. It shows, again, that infant mortality followed its own rhythm. Years of high infant mortality were instead years of whooping cough and, in particular, smallpox mortality (Bengtsson & Lindström 2003). Although some overlap with mortality in other age-groups did occur, like in 1772/3, 1831/2 and 1852/3, infant mortality often differed not only with respect to its annual changes but also causes of death. While peaks in infant mortality was typically due to outbreaks in smallpox and whooping cough, mortality crises among children and adults were primarily due to various fevers, typhus, pneumonia, malaria (1831/2), scarlet fever (1852/3) and others, several of which have a fatal outcome only for weak persons (Rotberg & Rabb 1985).

Food prices in Scania, known as the granary of Sweden, often peaked, as shown in Figure 3. Sometimes it was due to bad harvests in other parts of Sweden, like in 1797, sometimes due to demand from abroad, and sometimes due to bad local harvests. From the *harvest evaluations*, which are based on official inspections of the fields prior to the harvests, we know that Scania experienced famines in 1771 and 1783 with dramatically increasing prices as a consequence (Weibull 1923:115).

- Figure 3 here

While the harvests in the part of Scania we analyze here were below average in 1811, 1826, 1837, 1841, 1842, and 1853, these years should not be defined as weak years, even less as years of crises (Sommarin 1917, Vol 1:208-211). Thus the last famine in our area was in 1783. This makes the situation quite different from the rest of Sweden where four famines during the course of the 19th century occurred, namely in 1812, 1816, 1826, and 1841 (Sommarin 1917, Vol 1:208-211).

Information on temperature stems from daily observations in the city of Lund located 10-25 kilometres from the five parishes we analyze, with the exception of the years 1821-1833, for which we use data for Copenhagen. Winters are on average mild and summers not very hot, as shown in Figure 4. Still, the winters of 1785, 1789, 1799, 1800, 1809, and 1845, were very cold with monthly averages below 5 degrees centigrade, occasionally below 10 degrees. Cold winters were not only hard for humans as people risked running out of stored firewood, but also for the cattle. In hard winters, as food became more and more scarce, the farmers were left with no other option than to feed them on grain, forcing poor people to bake *barkbröd* (bark bread) as was the case in 1727 (Weibull 1923:115).

- Figure 4 here

To summarize, food prices are higher than during surrounding years in all years with mortality crises, except for 1832 and 1852, but very high prices are also found in numerous years with no crises (Figure 3). Winters were sometimes colder during a mortality crisis, sometimes not, and quite cold in many other years as well, like in the beginning of the nineteenth century with no excess mortality as a consequence (Figure 4). Thus, the economic and climatic conditions during the five mortality crises varied and no common pattern is easily identified, and conditions in other years were sometimes equally bad without causing the mortality to peak. Succeeding years of high prices, bad harvests and harsh winters were rare and not systematically related to the mortality crises.

From our previous analyses we know that excess mortality among children in ages 1 to 15 years rose by 73 percent during years of mortality crises, defined as two succeeding years of high mortality in late eighteenth and nineteenth century rural Scania. This by far exceeds the increase in infant mortality but roughly equals the rise in adult mortality (Bengtsson & Broström 2009). We found strong evidence that food prices have a much stronger effect on mortality during years of mortality crises than during other years, for which the effect is close to zero. The effects of temperature was, however, not significant. We have also previously found very strong effects of presence of parents; children losing a parent experienced several times higher mortality than children with parents present (Bengtsson 2004), a pattern found in many other places as well (for an overview, see Oris, Derosas, & Breschi 2004).

Methods

In the analyses, we use mainly two (non-standard) approaches, first a *proportional hazards model* (Cox 1972) with the extra twist of a *counter-matching nested case-control design* (Langholz & Borgan 1995). The purpose of the counter-matching is two-fold; a balanced composition with respect to certain covariates in each risk set is achieved, and the risk set sizes are drastically reduced, thus easing the computational burden. In the analysis, the matched sampling in the risk sets must be accompanied by weights inversely proportional to the probability of being selected. Risk set sizes are typically reduced from around 5000 to 100 each. The proportional hazards model assumes that the relative effect on mortality of any covariate is constant over age. However, the model allows time-varying covariates. It is very important to check the underlying assumptions behind this model, especially the proportionality assumption. We have therefore routinely tested all models for deviations from the proportionality assumption. The test we have used is based on the correlation between log(t) and the Schoenfeld residuals for each covariate. A high correlation indicates that the corresponding coefficient varies with time; in other words, that the hazards are not proportional (for details, see Therneau & Grambsch 2000:127–152). We found no sign of non-proportionality, neither on any of the covariates, nor globally.

The second approach is the *additive hazards model* (Aalen 1980, 1989), in combination with *dynamic path analysis* (see Aalen, Borgan, & Gjessing 2008:354).
The additive model allows for investigating the mediating effect of intermediate covariates in a causal framework. Following Aalen et al (2008:354-6), in Figure 1, the regression coefficient in a standard linear model of Y(t) on X(t) is denoted $\Theta_1(t)$. $\beta_1(t)$ and $\beta_2(t)$ are regression functions in the additive model referred to as the direct effects of X(t) and Y(t) on *d*N(t). The structural equations corresponding to Figure 1 are:

(1) $dN(t) = (\beta_0(t) + \beta_1(t)X(t) + \beta_2(t)\,Y(t))dt + dM(t)$

(2) $Y(t) = \Theta_0(t) + \Theta_0(t)X(t) + \varepsilon(t)$

The first equation is the classical Doob-Meyer decomposition and in the second, the error term $\varepsilon(t)$ is assumed independent of the martingales, denoted M(t), and X(t). Equations (1) and (2) are estimated by least squares at each t where $N(t) = 1$. Inserting the second equation in the first yields the marginal equation. The total effect of X(t) on $dN(t)$ is the indirect effects added to the direct effect:

$$(3) \quad \text{total effect} = (\beta_1(t) + \Theta_1(t)\, \beta_2(t))dt$$

The estimation procedures have been implemented in the package *eha* (Broström 2009) of the R statistical computing environment (R Development Core Team 2009). Test of non-linearity for the time-varying community variables (food prices and temperature) was done by categorizing, coding them as orthogonal polynomials and including them in the models.

Results

Table 1 shows the effects of food prices, and summer and winter temperatures on mortality in ages 1 to 15 years controlling for year at birth (to pick up a linear trend), sex, parish of residence and whether the person is born in the parish of residence or not for all years, whether crisis years or not. We also control for socio-economic status, that is, whether their parents belong to the landed group or not. The period is 1766 to 1860 and the parishes are Hög, Kävlinge, Halmstad, Sireköpinge, and Kågeröd. The number of deaths in age-group 1 to 15 years is 1,169. We are here using the Cox proportional hazards model with a counter-matching nested case-control design in order to get a balanced composition with respect to certain covariates in each risk set. This means not only that the parameter estimates are improved, but also that the risk set sizes are drastically reduced easing the computational burden.

- Table 1 here -

The parameter estimates for the fixed covariates are much as expected (Table 1). Being born one year later lowers mortality with 0.6 percent. Children not born in the parish but having in-migrated with their parents have 3.5 times higher mortality than those born in the same parish as they live. In addition, considerable differences between the parishes of residence exist. These results are much the same as in other studies; no or minor differences between sex and socio-economic status but substantial regional differences (see Bengtsson & Dribe 2008).

The effect of food prices is strong and as expected; the higher the price relative to surrounding years, the higher the mortality in the year to come. From our previous analyses of mortality, fertility, and migration, we know that the group of landless suffered from high food prices in the first half of the nineteenth century, less so in the periods before and after that (Bengtsson 2004; Bengtsson & Dribe 2005; Dribe 2000). Here, when studying the period 1766 to 1860, we find no evidence of any difference between the two socio-economic groups (interaction not significant, tables not shown here).

Concerning temperature, we do not find any effect on mortality among children. The result is surprising as we know that cold winters affected the mortality of parents (Bengtsson & Broström 2009).

In Tables 2 and 3, the same analysis is performed for years with high mortality ("crisis years") and for years with normal or low mortality ("good years"), respectively. Notable is the varying importance of food prices; they have a high impact during crisis years, but very low during good years. Winter temperature, on the other hand, has an effect during years with normal and low mortality, but not in crisis years. The effects of losing a parent also differ somewhat between crisis years and other years.

- Tables 2-3 here

With time-varying covariates, complicated patterns of mediation and intermediate factors may be present. Temperature, for example, may influence child mortality both *directly*, as cold winters increase the need for food and is also likely to increase crowding and thus making diseases spread more easily. It may, however, also affect mortality *indirectly*, through food prices, the reason being that a cold winter may influence the harvests of grains sown in the preceding fall.

One way of checking for mediation is to apply Aalen's linear hazards model, and continue along the lines of path analysis. This way, the *direct* and *indirect* effects could be separated. In Figures 5-7, the results of such analyses are shown, where the intermediate covariate is *food prices* when studying the effect of *winter temperature* on child mortality. The analyses are performed for all years, crisis years, and good years respectively. Note that the figures display *cumulative time-varying regression coefficients*, which means that we can identify not only whether the effect exist but also during what age-interval.

- Figures 5-7 here

The effects of winter temperature vary by age (Figure 5). Warm winters are reducing mortality in ages 1-5 years or so and the *direct* effect is dominating. During crisis years the total effects are small (Figure 6), while during good years there is a more distinct pattern of winter temperature on mortality, particularly in the ages 1-5 (Figure 7). Thus effects of winter temperature and food prices are independent of each other.

In Figures 8-10 the same kind of analyses are performed, with parent's death as the intermediate covariate in the relation between food prices and child mortality. The question is whether food prices affect child mortality directly, though access to food, or indirectly, through loss of a parent.

- Figure 8-10 here

The total effects of food prices are quite strong and influence not only in younger ages but throughout the entire age span, with a plateau in ages 3-5 years (Figure 8). Indirect effect is small and not significant. The effects are, however, only strong and significant during crisis years (Figure 9), not in other years (Figure 10).

Summary and Discussion

Causality is an important but complicated issue not only within social sciences in general but also within economic and historical demography. From studies at macro level, we know that environmental conditions, such as food prices and temperature had a strong impact both on fertility and mortality in the past. From micro studies, we know that the parents were of outmost importance to the health of their children, since extra-familial resources were few and inadequate. We also know that mortality in some years was simply far higher than in other years, and that such crisis years sometimes succeeded each other. The role of each of these factors is, however, somewhat unclear since they might not only influence mortality *directly*, but also *indirectly*. And they might influence mortality during crisis years differently from other years.

Temperature, may, for example, have a direct impact on mortality. Heating could be a problem during cold winters, hence making more food and timber needed, and creating crowding. It may also influence food prices since the development of the grain sown during the preceding fall depends on the temperature. Thus, when estimating the effects of temperature on mortality, one has not only to take in account the direct effects, but also the mediating effects of food prices. Likewise, while we know that both food prices and loss of a parent has a strong influence on mortality among children, we also know that food prices have a strong impact on the health of the parents.

We have therefore applied Aalen's linear hazards model to separate the *direct* and *indirect* effects from each other. The analyses are performed for all years, crisis years, and good years respectively, in order to understand the specificities of mortality crises. We have generally found that the *direct* effects are dominating. The direct effects of winter temperatures are far stronger that the indirect effects, via food prices. The direct effects of food prices are far stronger than the indirect effects, via parental deaths. We have also found that the causal mechanisms during crisis years are quite different from other factors, and not only in scale. While food prices are much more important than temperature in crisis years, it is the other way around in other years. The impact of parental deaths also differs, but here it is more a question of magnitude. Mothers become much more important during crisis years, as shown in our application of Cox proportion hazards models with counter-matching nested case-control design.

Acknowledgments

We kindly acknowledge the use of data from the Scanian Demographic Database, which is a collaborative project between the Regional Archives in Lund and the Centre for Economic Demography at Lund University. Tommy Bengtsson is grateful for financial support from the Linnaeus Centre for Economic Demography, Lund University as well as from the Swedish Research Council. Göran Broström was financially supported by The Bank of Sweden Tercentenary Foundation.

References

Aalen, O.O. (1980), A model for non-parametric regression analysis of life times. In W. Klonecki, A. Kozek, & J. Rosinski (Eds.), *Mathematical Statistics and Probability Theory*, Volume 2 of Lecture Notes in Statistics, 1-25.: Springer-Verlag, New York.

Aalen, O.O. (1989), 'A linear regression model for the analysis of life times', *Statistics in Medicine* 7, 1121-1137.

Aalen, O.O., Borgan, O. & Gjessing, H.K. (2008), *Survival and Event History Analysis: A Process Point of View*, Springer, New York.

Allen, R., Bengtsson, T. & Dribe, M. (Eds.) (2005), *Living Standards in the Past: New Perspectives on Well-Being in Asia and Europe*, Oxford University Press, Oxford.

Banggaard, G. (2002), 'Sygdom og Sundhet: Offentlige ingreb og deres virkninger i Sydsverige, c. 1750–1894', Lund Papers in Economic History no. 76, Department of Economic History, Lund.

Bengtsson, T. (1993a), 'A Re-Interpretation of Population Trends and Cycles in England, France, and Sweden, 1751–1860', *Histoire et Mésure* VIII.1, 93–115.

Bengtsson, T. (1993b), Combined time-series and life event analysis: The impact of economic fluctuations and air temperature on adult mortality by sex and occupation in a Swedish mining parish. In D.S. Reher & R. Schofield (Eds.), *Old and New Methods in Historical Demography*, Clarendon Press/ Oxford University Press, Oxford, England/ New York, pp. 239–258.

Bengtsson, T. (2000), Inequality in death: Effects of the agricultural revolution in southern Sweden, 1975–1865. In T. Bengtsson & O. Saito (Eds.), *Population and Economy: From Hunger to Modern Economic Growth*, Oxford University Press, Oxford, pp. 301–334.

Bengtsson, T. (2004), Mortality and Social Class in Four Scanian Parishes. In T. Bengtsson, C. Campbell & J. Z. Lee, et al., *Life under Pressure. Mortality and Living Standards in Europe and Asia 1700–1900*, MIT Press, Cambridge, MA. pp. 37–41.

Bengtsson, T. & Broström, G. (1997), 'Distinguishing Time-Series Models by Impulse Response: A Case Study of Mortality and Population Economy', *Historical Methods* 30:4, 165–171.

Bengtsson, T. & Broström, G. (2009), 'Mortality Crises in Rural Southern Sweden 1766–1860', Paper presented at the IUSSP International Seminar on Demographic Responses to Sudden Economic and Environmental Change, Kashiwa, Chiba, Japan, 21-23 May 2009

Bengtsson, T., Campbell, C. & Lee, J. Z. et al. (2004), *Life under Pressure. Mortality and Living Standards in Europe and Asia 1700–1900,* MIT Press, Cambridge, MA.

Bengtsson, T & Dribe, M. (1997), 'Economy and Demography in Western Scania', Eurasia Project on Population and Family History Working Paper Series, No. 10, International Research Centre for Japanese Studies, Kyoto.

Bengtsson, T. & Dribe, M. (2005), New evidence on the standard of living in Sweden during the 18th and 19th centuries: Long-term development of the demographic response to short-term economic stress among landless in western Scania. In R. Allen, T. Bengtsson & M. Dribe (Eds.), *Living Standards in the Past: New Perspectives on Well-Being in Asia and Europe*, Oxford University Press, Oxford, pp. 341–371.

Bengtsson, T. & Dribe, M. (2008), 'Socioeconomic Status and Mortality during the Mortality Transition: A Micro-level Study of Age-specific Mortality in Rural Southern Sweden 1815-1894', Paper presented at IUSSP seminar The Emergence of Social Differences in Mortality: Time Trends, Causes, and Reactions, May 29-30, 2008, Alghero, Italy.

Bengtsson, T. & Lindström, M. (2003), 'Airborne infectious diseases during infancy and mortality in later life in southern Sweden, 1766–1894', *International Journal of Epidemiology* 32, 286–294.

Bengtsson, T. & Ohlsson, R. (1985), Population and Economic Fluctuations in Sweden 1749–1914. In T. Bengtsson, G. Fridlizius & R. Ohlsson (Eds.), *Pre-Industrial Population Change. The Mortality Decline and Short-Term Population Movements*, Almqvist & Wiksell International, Stockholm, pp. 277–328.

Bengtsson, T. & Reher, D. (1998), Short and medium term relations between population and economy. In C-E. Núñes (Ed.), *Debates and Controversies in Economic History*, Proceedings of the Twelfth International Economic History Congress, Madrid.

Bengtsson, T. & Saito, O. (Eds.) (2000), *Population and Economy: From Hunger to Modern Economic Growth*, Oxford University Press, Oxford.

Broström, G. (2009), *eha: Event History Analysis,* R package version 1.2-6.

Carlsson, S. (1968), *Yrken och samhällsgrupper. Den sociala omgrupperingen i Sverige efter 1866,* Almqvist & Wiksell, Stockholm.

Cox, D. (1972), 'Regression models and life-tables (with discussion)', *Journal of The Royal Statistical Society, Series B* 34, 187–220.

Dribe, M. (2000), *Leaving Home in a Peasant Society. Economic Fluctuations, Household Dynamics and Youth Migration in Southern Sweden, 1829–1866*, Almqvist & Wiksell International, Södertälje.

Dupâquier, J. (1989), Demographic crises and subsistence crises in France, 1650–1789, In J. Walter & R. Schofield (Eds.), 'Famine, disease and the social disorder in early modern society', Cambridge University Press, Cambridge, pp. 189–200.

Galloway, P.R. (1988), 'Basic patterns in annual variations in fertility, nuptiality, mortality, and prices in pre-industrial Europe', *Population Studies* 42, 275–303.

Hernan. M.A., Lanoy, E., Costagliola, D. & Robins, J.M. (2006), 'Comparison of dynamic treatment regimes via inverse probability weighting', *Basic & Clinical Pharmacology & Toxicology*, 98:237-242.

Langholtz, B. & Borgan, O. (1995), 'Counter-Matching: A Stratified Nested Case-Control Sampling Method', *Biometrika,* 82:69-79.

Lee, R.D. (1981), Short-term variation: Vital rates, prices and weather. In E.A. Wrigley & R. S. Schofield (Eds.), *The Population History of England, 1541–1871. A Reconstruction*, Edward Arnold, London, pp. 356–401.

Lee, R.D. (1990), 'The demographic response to economic crises in historical and contemporary populations', *Population Bulletin of the United Nations* 20, 1–15.

Lundh, C. (1998), 'Servant migration in the early nineteenth century', *Journal of Family History* 24, 53–73.

Olofsson, J. (1996), *Arbetslöshetsfrågan i historisk belysning. En diskussion om arbetslöshet och social politik i Sverige 1830-1920*, Lund University Press, Lund.

Oris, M., Derosas, R, & Breschi, M. (2004), Infant and Child Mortality. In T. Bengtsson, C. Campbell & J. Z. Lee, et al., *Life under Pressure. Mortality and Living Standards in Europe and Asia 1700–1900*, MIT Press, Cambridge, MA. pp. 359–398.

R Development Core Team (2009), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. *http://www.R-project.org

Richards, T. (1984), Weather, nutrition and the economy: The analysis of short run fluctuations in births, deaths and marriages, France 1740–1909. In T. Bengtsson, G. Fridlizius & R. Ohlsson (Eds.), *Pre-Industrial Population Change. The Mortality Decline and Short-Term Population Movements*, Almquist & Wiksell International, Stockholm, pp. 357–390.

Rotberg, R. & Rabb, T.K. (Eds.) (1985), *Hunger and History: The Impact of Changing Food Production and Consumption Patterns on Society*, Cambridge University Press, Cambridge.

Skoglund, A-M. (1992), *Fattigvården på den svenska landsbygden år 1929*, School of Social Work, Stockholm.

Sommarin, E. (1917), *Det skånska jordbrukets ekonomiska utveckling 1801-1914*, Del I, Skrifter utgivna av Skånska Hushållningssällskapen. Berlingska boktryckeriet, Lund.

Therneau, T.M., & Grambsch, P.M. (2000), *Modeling Survival Data: Extending the Cox Model*, Springer, New York.

Tromp, S. (1963), *Medical Biometeorology*, Elsevier, Amsterdam.

Utterström, G. (1957), *Jordbrukets arbetare*, Tidens Förlag, Stockholm.

Weibull, C-G. (1923), *Skånska jordbrukets historia intill 1800-talets början*, Skrifter utgivna av Skånska Hushållningssällskapen. Gleerups, Lund.

Åmark, K. (1915), *Spannmålshandel och spannmålspolitik i Sverige 1710–1830*, Isaac Marcus, Stockholm.

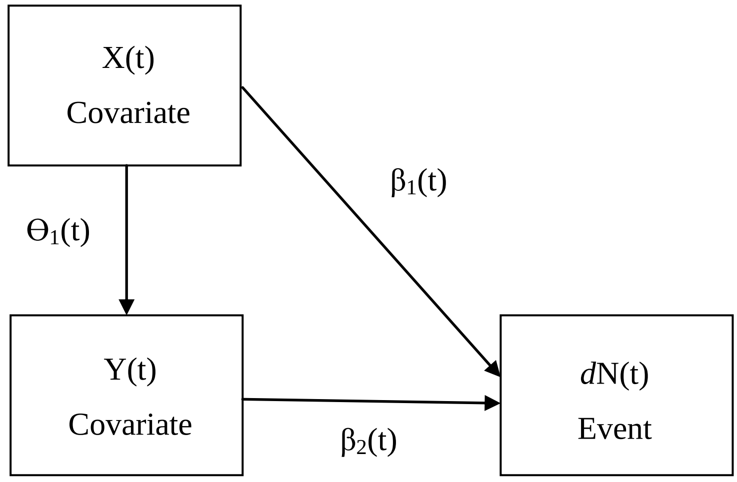


Figure 1. Path diagram for a single jump in a counting process illustrating problems of causality.

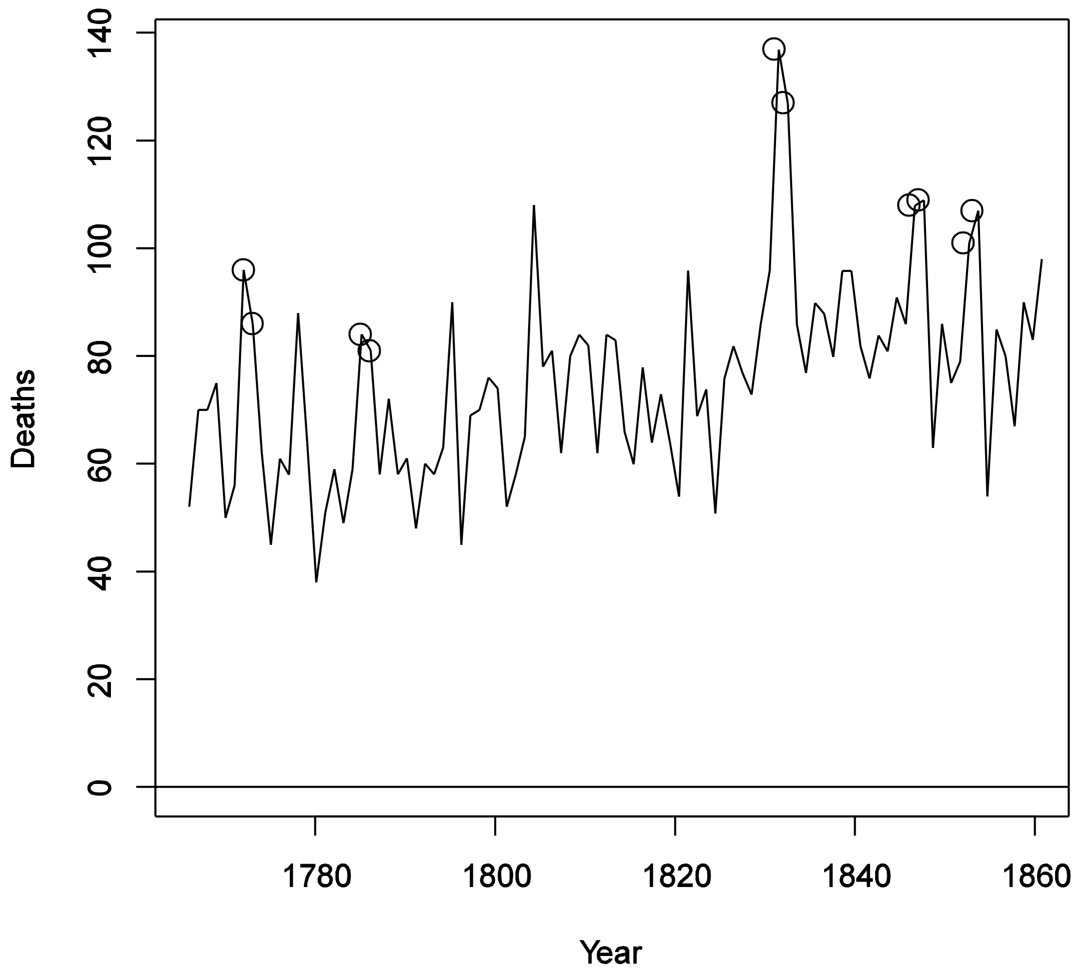


Figure 2. Total number of deaths by year in five parishes, 1766-1860. Circled years are airs of successive years having very high mortality.

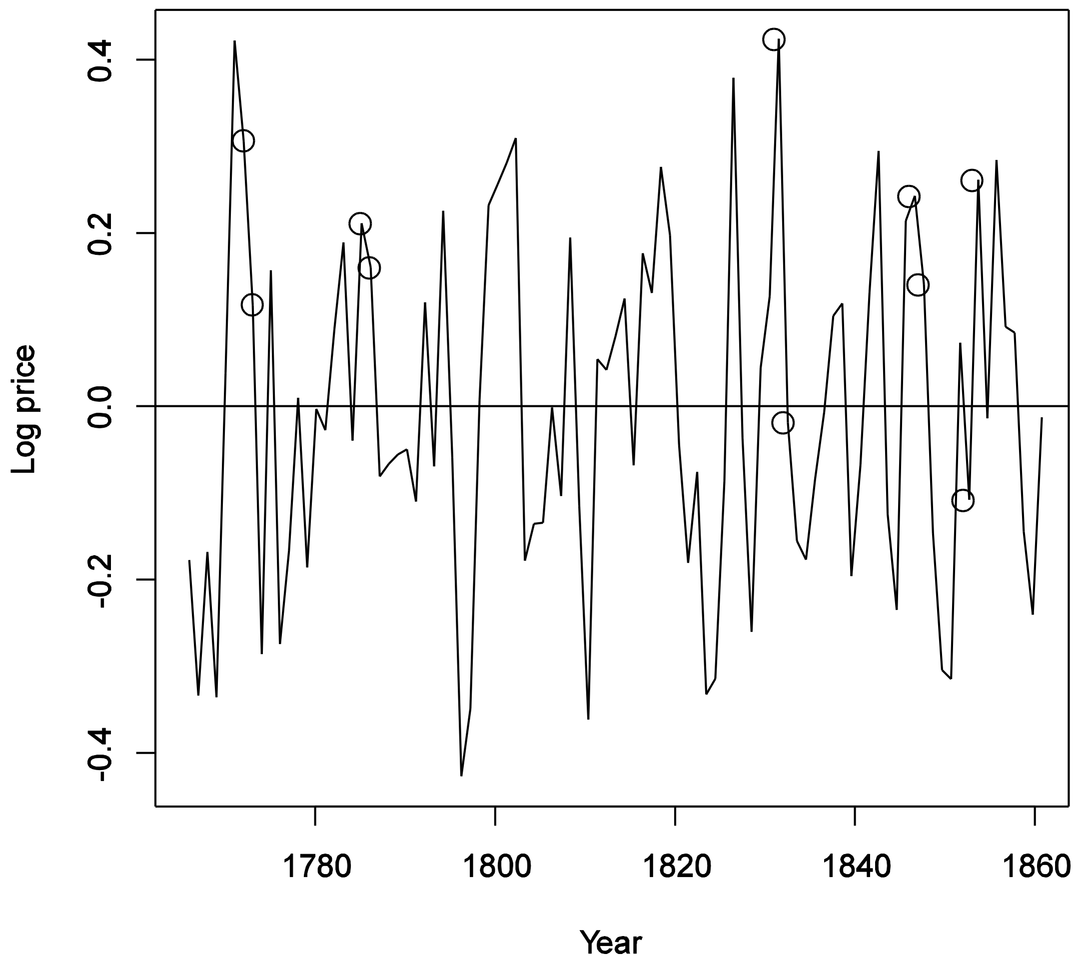


Figure 3. Yearly local food prices, 1766-1860. Logged, detrended prices of rye. Circled years are pairs of successive years having very high mortality.

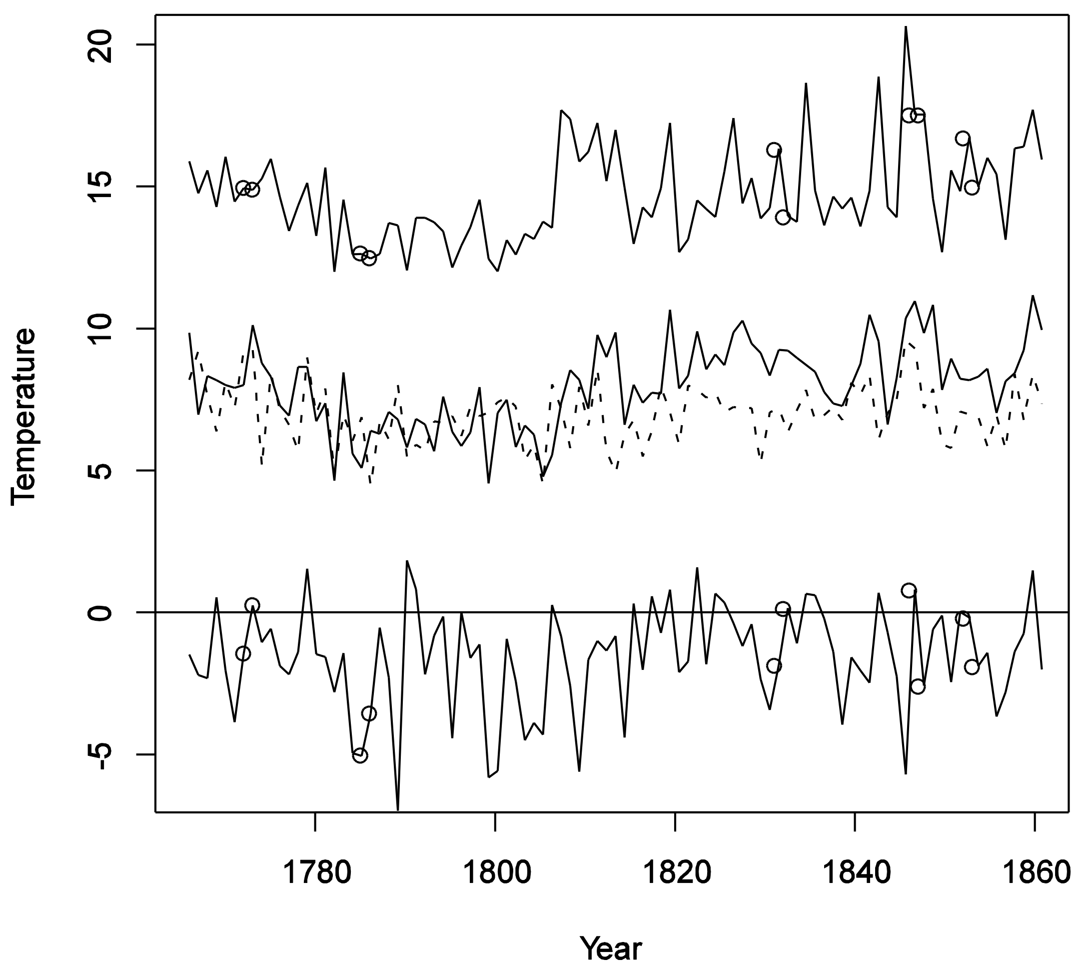


Figure 4. Monthly averages in temperature (centigrade) in Lund, 1766–1860. From top to bottom: summer (July and August), spring (solid line, April, May, and June), fall (dashed line, September, October, and November), and winter (January, February, March, and December previous year). Circled years are pairs of successive years having very high mortality.

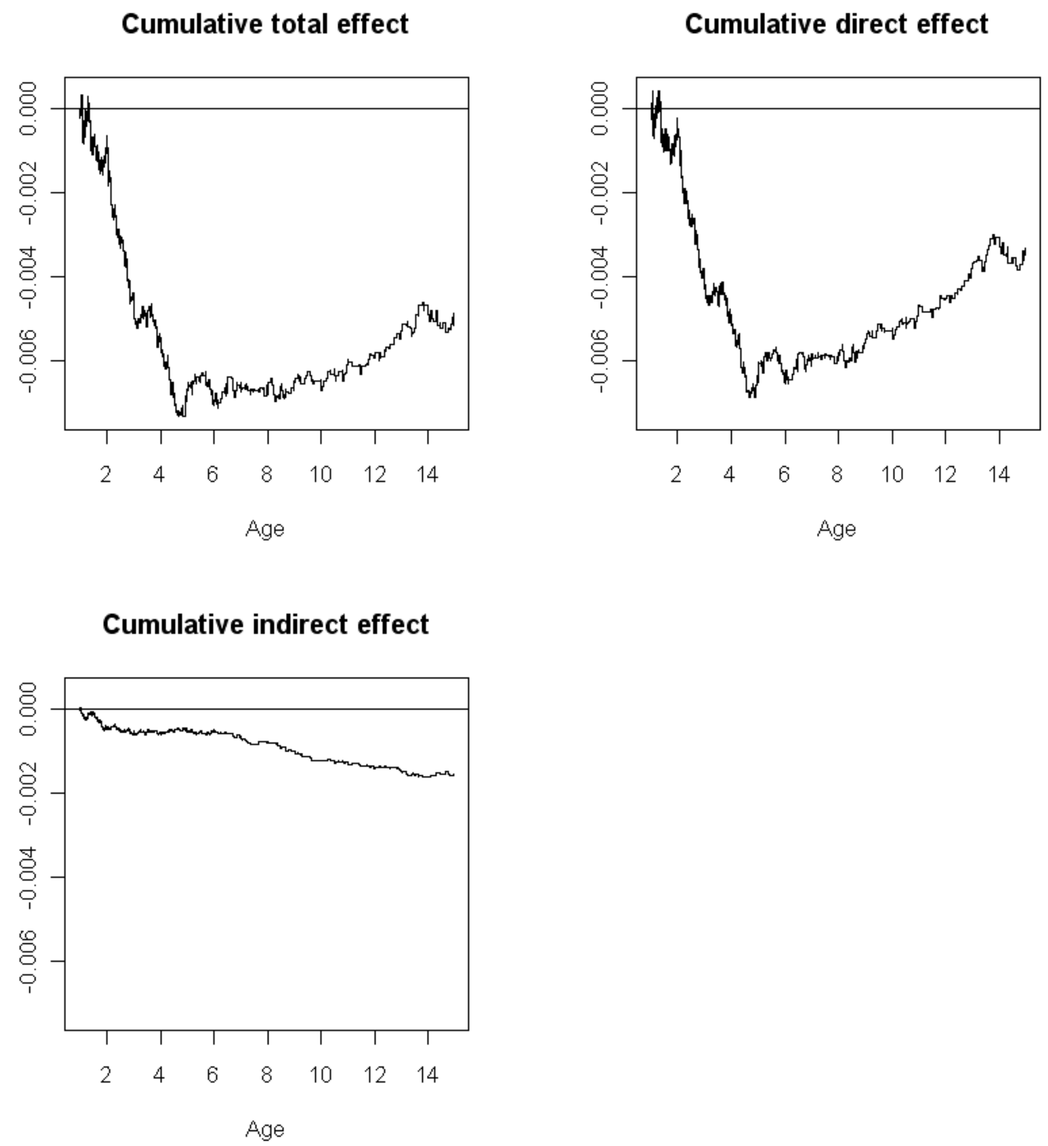


Figure 5. Effect of winter temperature on mortality next year, mediated by food prices. All years.

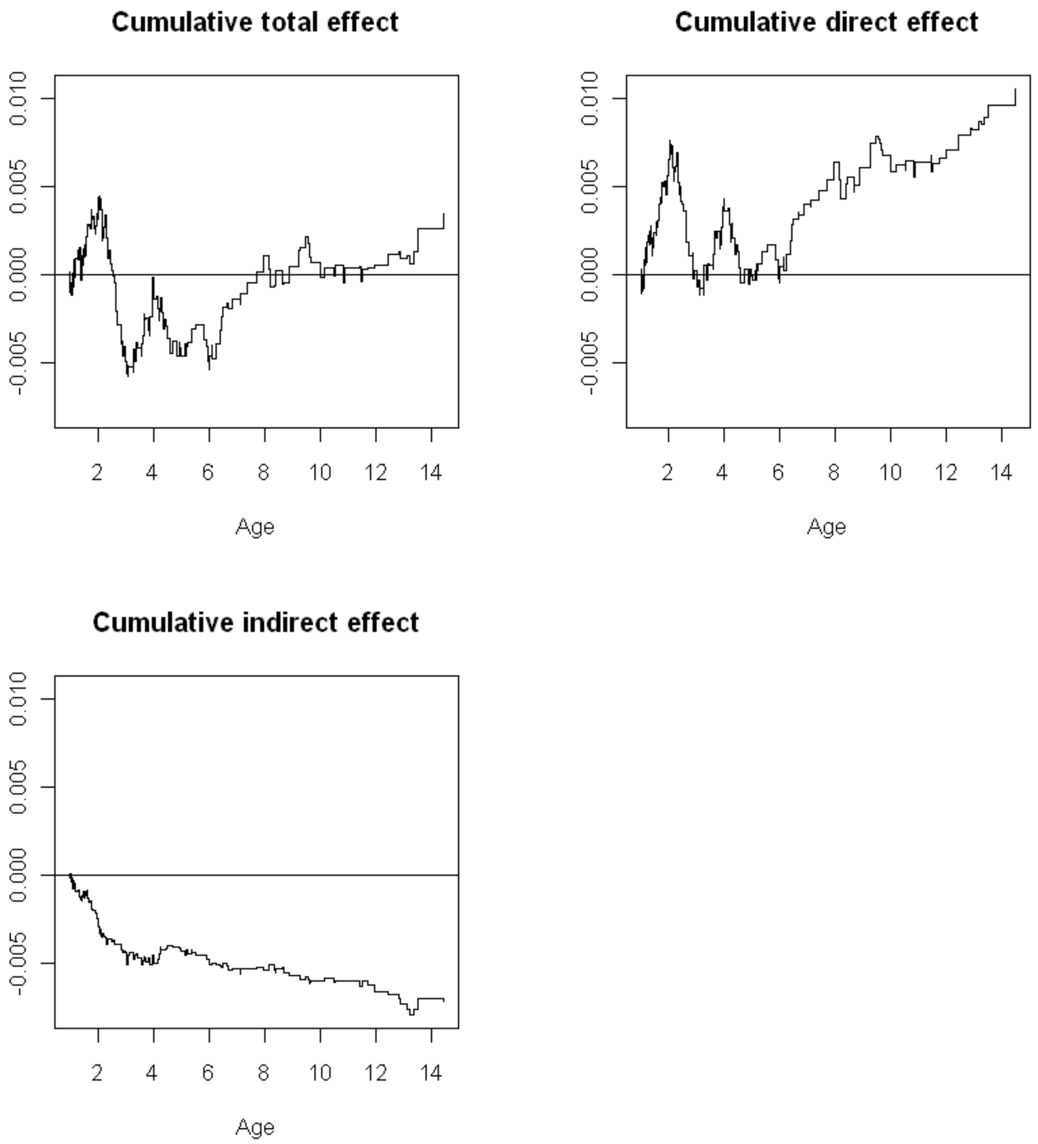


Figure 6. Effect of winter temperature on mortality next year, mediated by food prices. Crisis years.

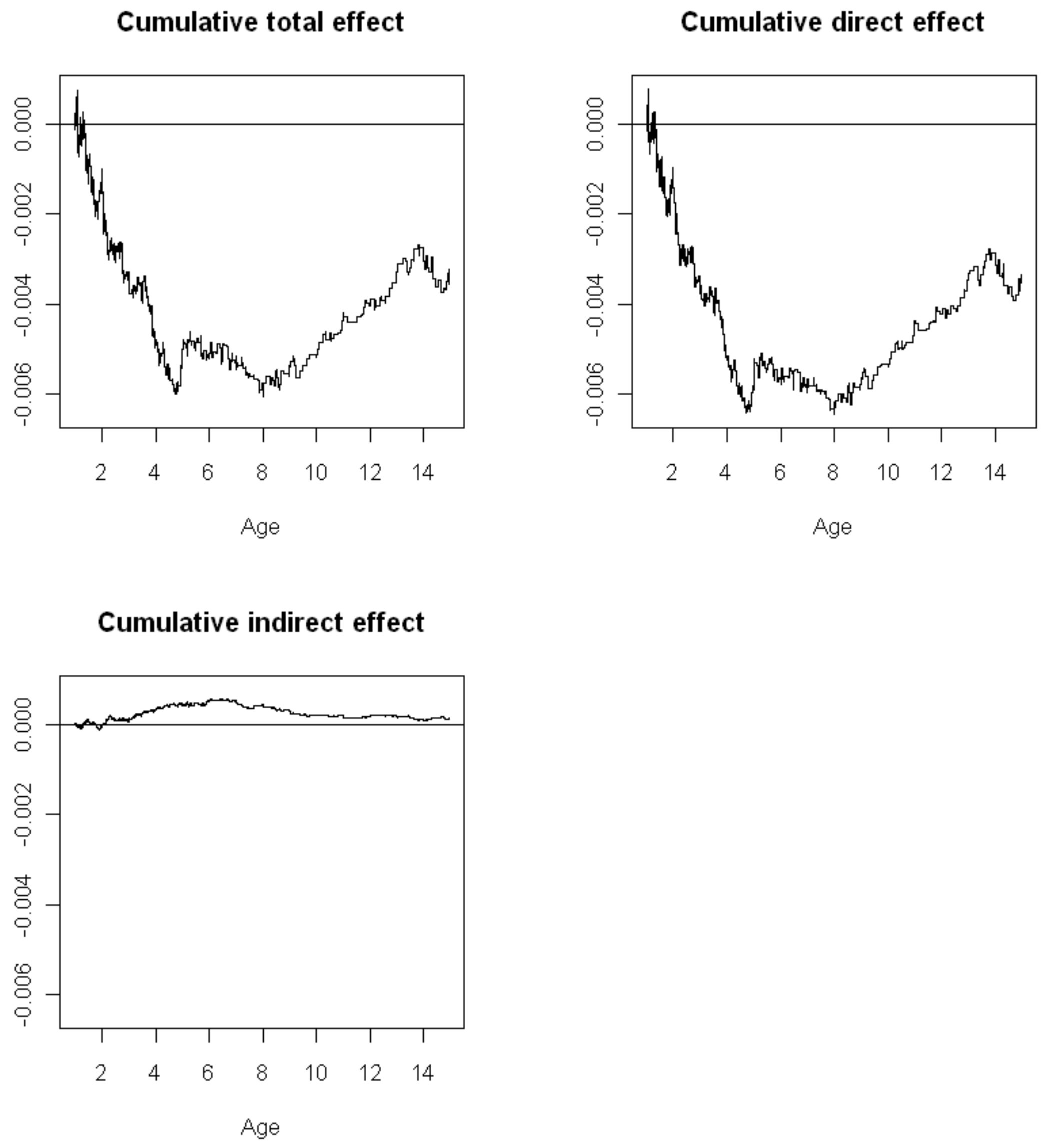
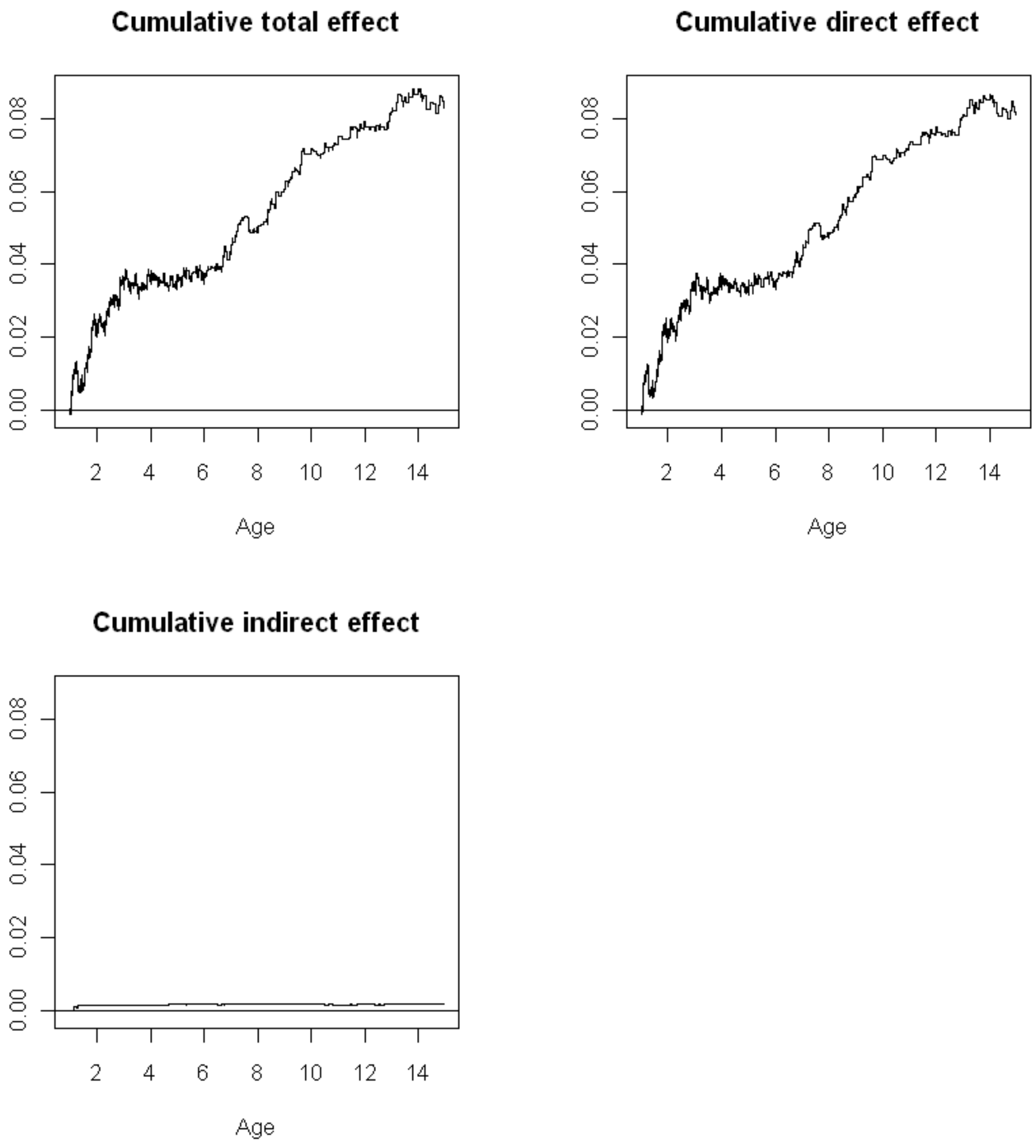


Figure 7. Effect of winter temperature on mortality next year, mediated by food prices. Good years.



.

Figure 8. Effect of food prices on mortality, mediated by parent's death. All years.

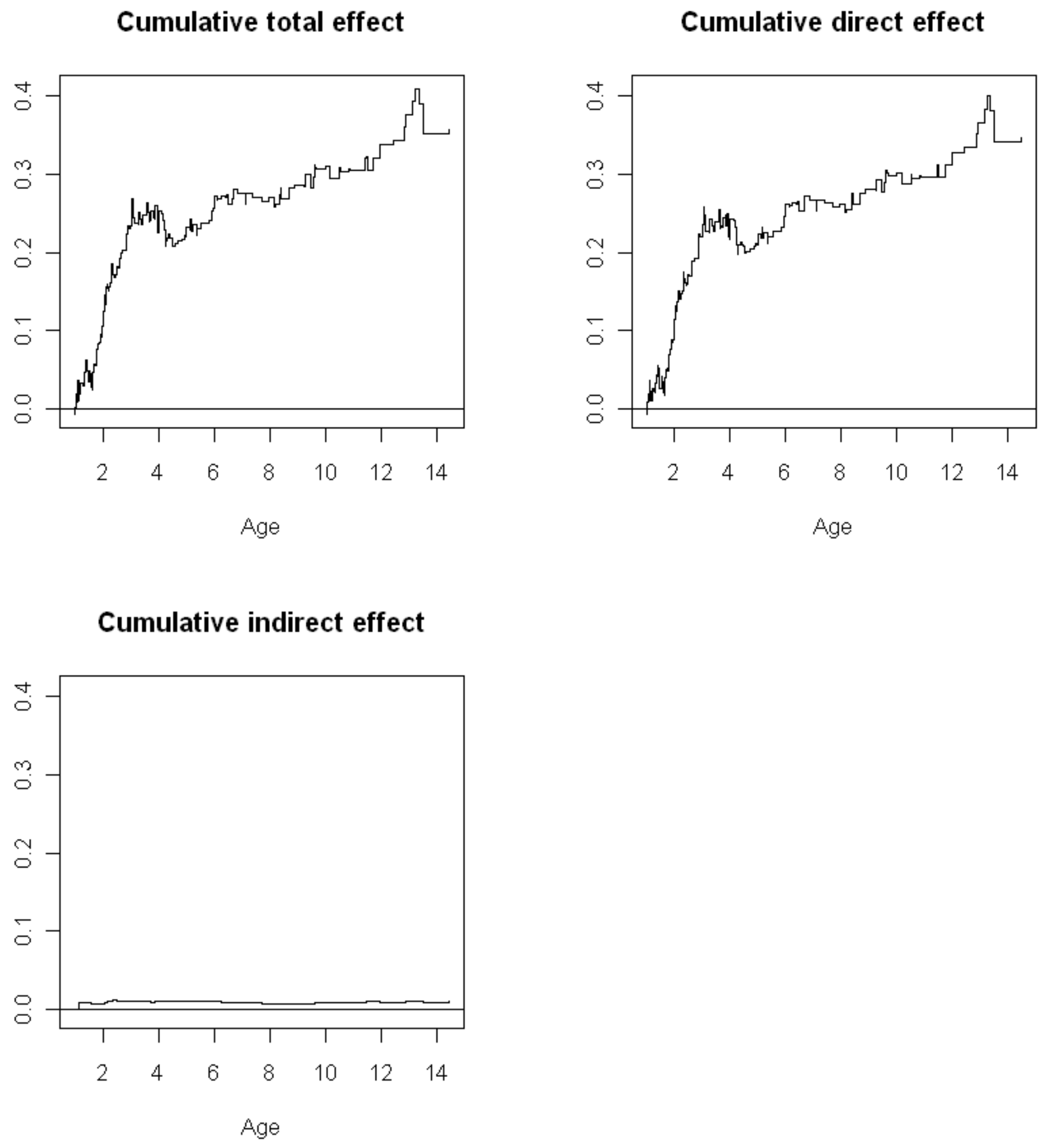


Figure 9. Effect of food prices on mortality, mediated by parent's death. Crisis years.

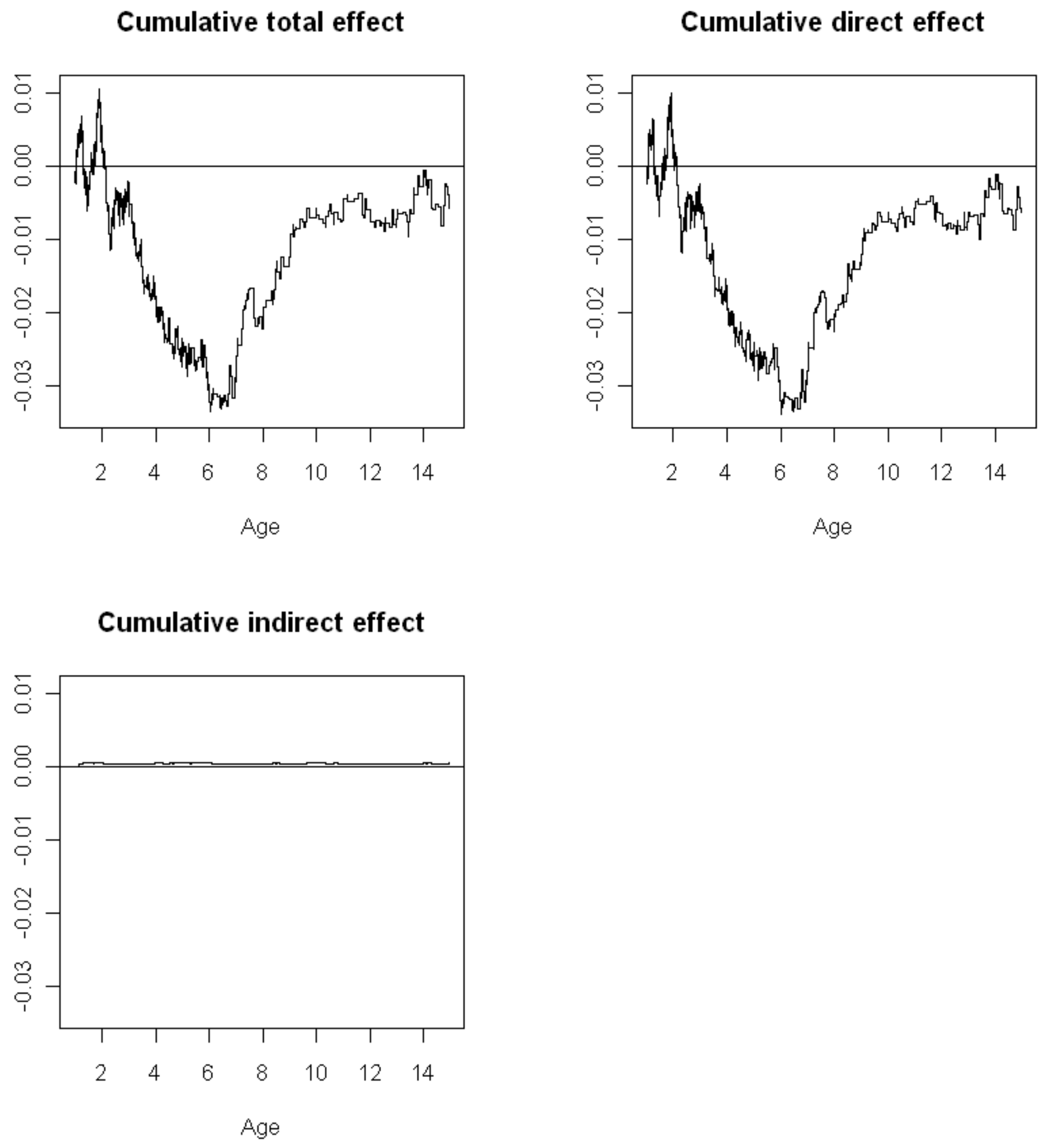


Figure 10. Effect of food prices on mortality, mediated by parent's death. Good years.

Table 1. The effect of parental deaths, food prices, winter and summer temperature on child mortality in ages 1 to 15 after controlling for sex, birth date, parish of residence, parish of birth, socioeconomic status of parents. All years.

Covariate	Mean	Rel.Risk	Wald p	L-R p
Birthdate	1813.909	0.994		0.000
Parish				0.000
Hög	0.102	1 (reference)		
Kävlinge	0.123	1.243	0.073	
Sireköpinge	0.179	0.946	0.637	
Halmstad	0.192	0.891	0.324	
Kågeröd	0.404	0.422	0.000	
Not born in parish	1.312	3.480		0.000
SES				0.448
landless	0.595	1 (reference)		
landed	0.405	1.049		
Sex				0.355
male	0.506	1 (reference)		
female	0.494	0.947		
Mother died	0.011	2.556		0.000
Father died	0.017	1.784		0.009
Winter temperature	-1.523	0.995		0.742
Summer temperature	14.818	0.998		0.922
Food prices	0.001	1.628		0.001

Events	1169
Overall p-value	0.000

Table 2. The effect of parental deaths, food prices, winter and summer temperature on child mortality in ages 1 to 15 after controlling for sex, birth date, parish of residence, parish of birth, socioeconomic status of parents. Crisis years.

Covariate		Mean	Rel.Risk	Wald p	L-R p
Birthdate		1821.733	0.996		0.218
Parish					0.008
	Hög	0.111	1 (reference)		
	Kävlinge	0.129	1.146	0.633	
	Sireköpinge	0.189	1.213	0.459	
	Halmstad	0.189	0.953	0.858	
	Kågeröd	0.382	0.571	0.041	
Not born in parish		1.341	2.466		0.000
SES					0.604
	landless	0.620	1 (reference)		
	landed	0.380	0.924		
Sex					0.860
	male	0.506	1 (reference)		
	female	0.494	1.024		
Mother died		0.014	3.808		0.002
Father died		0.023	1.343		0.539
Winter temperature		-1.389	1.068		0.176
Summer temperature		15.744	0.974		0.570
Food prices		0.165	2.493		0.053

Events	217
Overall p-value	0.000

Table 3. The effect of parental deaths, food prices, winter and summer temperature on child mortality in ages 1 to 15 after controlling for sex, birth date, parish of residence, parish of birth, socioeconomic status of parents. Good years.

Covariate		Mean	Rel.Risk	Wald p	L-R p
Birthdate		1812.895	0.993	0.001	0.000
Parish					0.000
	Hög	0.101	1 (reference)		
	Kävlinge	0.123	1.213	0.148	
	Sireköpinge	0.177	0.844	0.199	
	Halmstad	0.193	0.857	0.234	
	Kågeröd	0.406	0.376	0.000	
Not born in parish		0.308	3.722		0.000
SES					0.324
	landless	0.592	1 (reference)		
	landed	0.408	1.070		
Sex					0.236
	male	0.506	1 (reference)		
	female	0.494	0.926		
Mother died		0.011	1.910		0.037
Father died		0.017	1.837		0.015
Winter temperature		-1.541	0.968		0.074
Summer temperature		14.698	0.972		0.185
Food prices		-0.020	0.946		0.751

Events	952
Overall p-value	0.000