Unequal lands

Soil type, nutrition, and child mortality in southern Sweden, 1850-1914

Hedefalk, Finn; Quaranta, Luciana; Bengtsson, Tommy

Research Article

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Finn Hedefalk

Luciana Quaranta

Tommy Bengtsson

Contents

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Finn Hedefalk[1,2]

Luciana Quaranta[2]

Tommy Bengtsson[2]

Abstract

BACKGROUND
Child mortality differed greatly within rural regions in Europe before and during the mortality transition. Little is known about the role of nutrition in such geographic differences, and about the factors affecting the nutritional status and hence the disease outcomes.

OBJECTIVE
Focusing on nutrition, we analyse the effects of soil type, used as an indicator of the farm-level agricultural productivity and hence of nutritional status, on mortality of children aged 1–15 living in five rural parishes in southern Sweden, 1850–1914.

METHODS
Using longitudinal demographic data combined with unique geographic microdata on residential histories, the effect of soil type on mortality risks are analysed considering as outcome all-cause mortality and mortality from nonairborne and airborne infectious diseases.

RESULTS
Soil type primarily affected the mortality of farmers' children, but not labourers' children. Particularly, farmers' children residing in areas with very high proportions of clayey till (75–100% coverage) experienced lower risks of dying compared to children residing in areas with other soil types such as clay and sandy soils.

CONCLUSIONS
Certain soil types seem to have influenced agricultural productivity, which in turn affected the nutrition of farmers' children and thus their likelihood of dying. The results

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[1] Department of Physical Geography and Ecosystem Science, Lund University, Sweden.
E-Mail: finnhedefalk@gmail.com.
[2] Centre for Economic Demography and Department of Economic History, Lund University, Sweden.

indicate the relatively important role of nutrition as a mortality predictor for these children.

CONTRIBUTION
As, to our knowledge, the first longitudinal study at the microlevel that analyses the effects of soil type on mortality in a historical rural society, we contribute to the literature on the role of nutrition on the risk of dying in a preindustrial society.

1. Introduction

This paper studies the role of nutrition by analysing the effects of soil type on mortality of children living in five rural parishes in southern in Sweden, for the period 1850–1914. Mortality differed greatly among regions in Europe before and during the mortality decline. These differences were not only common between rural and urban areas, but also between nearby rural areas (Bengtsson and Dribe 2010, 2011; Claësson 2009; Gregory 2008; Van Poppel, Jonker, and Mandemakers 2005). Studies covering the same area and a similar period as this paper have found large differences between parishes in both childhood and adult mortality after controlling for socioeconomic and other family factors. In fact, the regional differences were often larger than the socioeconomic ones, indicating that place was a stronger determinant of mortality than family factors (Bengtsson and Dribe 2010, 2011). Possible explanations for the mortality differences are variations in the distribution of risk factors related to exposure or resistance to diseases, or both.

Although widespread epidemics and other highly virulent diseases (both with a low socioeconomic gradient) had decreased in 19th century Sweden, they were still a major cause of death (Bengtsson and Lindstrom 2000; Quaranta 2013). Several factors affecting exposure to such diseases in the period considered in this study varied across regions; for example, access to safe water and sanitation, housing conditions, population density, public health implementations, poor relief, and breast-feeding practices (Brändström 1984; Brändström, Edvinsson, and Rogers 2002; Claësson 2009; Floud et al. 2011; Kintner 1985; Lazuka, Quaranta, and Bengtsson 2016; Woods, Watterson, and Woodward 1988). The spread of contagious diseases may also have been influenced by characteristics of the environment such as topography and accessibility through communication networks, which may determine the interaction patterns between people. In addition, microclimate (e.g., temperature and humidity), affected by soil conditions, topography, or other factors, could possibly influence exposure to diseases such as the common cold and respiratory diseases (Munro et al. 1997). Lastly, vectorborne diseases such as malaria were common in Europe until the

mid-19th century (they disappeared primarily because of climate variations, drainage of wetlands, increased living standards, and better nutrition (Lindgren and Jaenson 2006)). Wetlands and areas with certain beneficial soil conditions served as habitats for mosquitos transmitting malaria; therefore, residing close to such areas would likely increase the exposure to diseases (Dobson 1994; Patz et al. 1998; Schröder and Schmidt 2008).

In the beginning of the 19th century, diseases affected by nutritional status became an increasingly important determinant of mortality in Sweden. This trend was a consequence of the mortality decline in which a reduction in the virulence of the pathogens likely occurred (Fridlizius 1984). Low nutritional intake is associated with decreased immune response and increased incidence of diseases that are harmless to a well-nourished person (Rotberg and Rabb 1983: 304–308; Schaible and Kaufmann 2007; Goldstein, Katona, and Katona-Apte 2008; Rodríguez, Cervantes, and Ortiz 2011). Nutritional status is in fact important in determining the response and survival of the human host to organisms that cause disease (McKeown, Brown, and Record 1972). Common factors that affected nutritional status were income and wealth, which in preindustrial rural societies were mostly determined by the ability of individuals to support themselves from the land they owned or worked on. In addition to the size of the farm and its arable land, variations in the natural environment such as soil conditions could affect farm-level productivity and hence potential income from the land (Bohman 2010; Brunt 2004; Puleston and Tuljapurkar 2008). Such differences in farm-level output would therefore manifest themselves as a socioeconomic gradient in mortality. Mortality differences among social classes were, however, small for adults until the 20th century in Europe (Bengtsson and van Poppel 2011). On the other hand, socioeconomic mortality differences existed for children in the study area during the latter part of the time period considered in this study (Bengtsson and Dribe 2010), which indicates an influence of nutritional status, through wealth, on mortality.

The aim of this study is to better understand the role of nutrition on child mortality, in general, and in the mortality differences which have been found previously among the five Scanian parishes considered in this study (c.f. Bengtsson and Dribe 2010, 2011). Because large differences in mortality between rural areas have been found after controlling for various socioeconomic factors, there are indications of other factors in play that affect mortality. Such factors could be those that determine exposure to virulent diseases and that have a low social gradient. Alternatively, the commonly used measures of socioeconomic status may not fully capture differences found in the nutritional status of individuals.

Historical datasets (for rural areas) containing longitudinal and individual-level economic information on income and farm-level productivity are sparse, which is also the case for our study area. To overcome this problem, previous research has used

information about taxation and land type (e.g., manorial or freehold) to construct socioeconomic variables (Bengtsson 2004). For the period considered in this paper, however, taxation information may not fully capture farm-level productivity (cf. e.g., Svensson 2001). Therefore, as an additional measure of nutrition, we use information on the underlying soil type for each farm. Soil type is one core factor that affects the agricultural suitability and potential crop yield of an area (e.g., Fischer et al. 2002). In a rural society, where the main income source comes from the agricultural output of the land, soil type may indicate wealth and therefore nutritional status of individuals dependent on that land. In the study area of this paper, fertile and relatively manageable soils such as clayey till were likely more suitable in general for some of the commonly grown crops compared to the less fertile sandy soils and the heavy and less manageable clay soils (Eriksson et al. 2005; Bohman 2010: 61–62).

We estimate the soil type variable using individual-level longitudinal data from the Scanian Economic Demographic Database (SEDD) in combination with novel microlevel geographic data. Such information is available because we have recently linked individuals in the SEDD database to the property units they lived in for the period 1813–1914 (Hedefalk, Harrie, and Svensson 2015). Hence, we can combine detailed residential histories with detailed information on soil type for each property unit. This information can therefore be used as an estimate of agricultural production for individuals residing in the property units. Because soil types varied between and within regions, they may also explain some of the spatial mortality differences found previously between the five parishes.

We analyse the effects of soil type on mortality of children, from the age of 1 until they turn 15, for the period 1850–1914. Children aged 1–15 are studied because they were sensitive to malnutrition as well as to environmental factors (Bengtsson 1999; Rocklov et al. 2014; Schumann et al. 2013; Wolleswinkel-van den Bosch et al. 2000) and the regional differences in mortality were usually larger among them (Van Poppel, Jonker, and Mandemakers 2005). As a sensitivity test, we also analyse infants (age 0–1) to compare the two age groups. The focus is, nevertheless, on child mortality; it is in general more dependent on family income and living conditions compared to infant mortality, which is mainly affected by care such as breastfeeding (e.g., Bengtsson 1999, 2004; Oris, Derosas, and Breschi 2004). Moreover, we expect that the impact of soil on child mortality will vary based on whether the family depended on their land for income and nutrition. Therefore, we categorize families into three groups: large-scale farmers, small- and medium-scale farmers (henceforth called farmers), and labourers (cf., Section 5.1). Using a rudimentary indicator based on taxation information and area of the properties in which individuals lived, we define farmers as those having land that was large enough to provide at least the majority of the earnings needed for subsistence. Families having smaller and less productive lands than farmers, including the landless,

are defined as labourers. Lastly, the large-scale farmers constitute a small group of the most well-off individuals.

We contribute to the literature on the role of nutrition and geographic context on the risk of dying in a preindustrial society by focusing on the following two hypotheses.

1) Our main hypothesis is that soil type is a measure of farm-level agricultural productivity and hence of nutritional status for the farmers' children; i.e., children of individuals owning or leasing land (labourers, who were mostly paid in money or in kind, as well as the large-scale farmers, should be less affected by soil type). We expect that children living on farms covered by relatively large areas of fertile and relatively manageable soils, such as clayey till, experienced lower mortality than children living on farms with less productive soils. We also expect stronger effects of soil type on mortality from nonvirulent and nutrition dependent diseases compared to highly virulent airborne-infectious diseases such as whooping cough and smallpox.

2) As an alternative hypothesis, soil type may instead be a measure of exposure to virulent diseases. If so, we expect soil to affect the mortality of all social groups equally. In addition, there should be stronger effects of soil on mortality from highly virulent airborne-infectious diseases.

To our knowledge, this is the first longitudinal study at the microlevel that analyses the effects of soil type on mortality in a historical rural society. Previous and related research has often used geographic macrodata on larger administrative units and therefore much detail has been lost. The main reason is that large historical datasets that links individuals to microlevel longitudinal geographic data is sparse. Note, however, that this study is exploratory in its nature due to the small number of available observations, which is a limitation of this study.

2. Previous research

The relationship in modern societies between productivity and environmental factors such as soil conditions has been well researched and several indices and models for soil conditions have been developed (Doran and Parkin 1994; Jaenicke and Lengnick 1997; Steduto et al. 2009). A broad literature is also available on the impacts of soil on human health. Such impacts can be direct or indirect. Direct effects are those foremost related to various pathogens contained in the soil (Oliver and Gregory 2015), which children are particularly exposed to (Hawley 1985). Indirect effects are primarily factors such as soil fertility that affect the quantity and quality of food produced (or the kind of food

that can be produced). In addition, trace elements and minerals in the soils are transferred to the food cultivated in it, which in turn affect the health of humans (Abrahams 2002; Oliver and Gregory 2015). For example the availability of elements such as iron, iodine, selenium, and zinc (Oliver and Gregory 2015), which are essential to human health, is highly linked to soil quality.

A few studies have tried to quantify the impact of local soil conditions on agricultural production patterns in a historical context (Allen 2008; Brunt 2004). For example, Brunt (2004) used village-level data to analyse the effects of technological developments and environmental factors on English agriculture in the 18th century. They found that technological applications such as drainage, turnip cultivation (which increased the humus content in the soil and thus reduced weeds), clover cultivation (which added nitrogen to the soil), and seed drills, increased yields substantially. As regards to the environmental factors, climate was shown to be a much more important factor affecting crop yield than soil quality (note, however, that the study used soil type data on a more aggregated level than what is used in our study). Furthermore, Allen (2008) analysed the importance of nitrogen in the soil and its relationship to yield in preindustrial England and found that nitrogen-fixing plants such as peas and beans accounted for approximately half of the yield increase during England's agricultural revolution. Thus, the local production pattern at each farm likely affected the fertility of the soil types. Moreover, there have been several theoretical demographic models developed that can be used to model feedbacks between food supply, vital rates, and labour availability in preindustrial societies. Using such models it is possible to analyse how environmental and soil conditions as well as human factors such as agricultural techniques and crop choices could affect mortality and fertility rates (Lee and Tuljapurkar 2008; Puleston and Tuljapurkar 2008). In a case study applying such models, Lee and Tuljapurkar (2008) found that both cultivated area and soil productivity positively affected population size for preindustrial societies.

Moreover, using parish-level data to analyse the effects on mortality of short term economic stress and how such effects differed among preindustrial farming regions, Dribe, Olsson, and Svensson (2011) found that, for the period 1750–1860, robustness against harvest failures differed greatly among the three common farming regions in Sweden (plain lands, brushwood, and forest lands). The effects diminished, however, because of the agricultural transformation in the beginning of the 19th century. Furthermore, Bohman (2010) analysed the impacts of natural conditions, markets, and technological developments on agricultural production patterns in preindustrial southern Sweden before and after the enclosures implemented during the period 1800–1850. The study found that, in addition to an increased importance of markets (due to growth of domestic and foreign markets), the implementation of enclosures increased the importance of natural conditions for individual farmers in the 19th century, and the

farming regions became less important. Consequently, the differences in productivity changed from being regional to local in line with the enclosures.

Finally, the effect of climate on mortality in preindustrial societies has been studied by combining microlevel and macrolevel data (Bengtsson and Broström 2010; Rocklov et al. 2014; Schumann et al. 2013). For example, Schumann et al. (2013), using parish-level data, found that for a rural region in northern Sweden in the 18th and 19th century, a high amount of autumn rain increased the total number of deaths for all age groups. The authors speculate that this higher level of rain reduced harvest quality and quantity, which in turn affected the nutritional status and hence susceptibility to infectious diseases. In addition, the rains may also have increased the spread of airborne diseases due to crowding (i.e., people stayed inside during rainy weather). Moreover, Bengtsson and Broström (2010) found that cold winters increased mortality among adults but not among children and infants, indicating that different age groups are affected by climate variations in different ways. Finally, as regards to soil type as a factor affecting the microclimate, Munro et al. (1997) studied the relationship between infant mortality and soil in England for the period 1981–1990. Using ward-level data they found that wards dominated by wet soils had 31.9% higher infant mortality than wards dominated by dry soils. The authors speculate that areas with wet soils in general contain humid and cold air, which may increase the risk of cold and other diseases for the infants and their mothers (Munro et al. 1997). Thus, soil type may affect the mortality of infants, although research shows that infant mortality is in general less dependent on environmental factors compared to child mortality.

3. Context and study area

The period of this study covers several changes in agricultural production and markets in Sweden. In the beginning of the 19th century, technical improvements such as better ploughs and the increased use of horses made it possible to cultivate lands that had not previously been suited for agriculture, foremost fertile, but heavy, clay soils, which had required more labour and which often became waterlogged. Such soils became increasingly used for grain production (Gadd 1983, 2011). Moreover, the implementation of enclosures increased the importance of natural conditions for the individual farmers in the 19th century. Before these land reforms, every field in a village was divided into smaller plots shared among farmers, and therefore soil conditions were quite equally distributed among farmers. After the land reforms, however, the plots of each landowner were consolidated into single landholdings, resulting in an increased variation of soil conditions between farmers (Bohman 2010). Furthermore, around 1880, livestock production became more important and commercial production

intensified. In Sweden as a whole, there were also decreased profits from grain production. This resulted in the cessation of new land reclamation that occurred up until 1880 (Morell 2011). In addition, with increased livestock production, fertilisers became more available, which likely improved soil conditions. There was also a more extensive use of new crops, which made it possible to increase crop yields on less productive soils. Moreover, with a more developed market, it was possible to produce a surplus of output. Large farms in the plain land regions could therefore better specialize in producing grains, whereas smaller family farms were better suited for livestock production (Pettersson 1989).

The study area covers five rural parishes located in Scania, the southernmost province in Sweden: Hög, Kävlinge, Kågeröd, Sireköpinge, and Halmstad (Figure 1). These parishes are not a representative sample of Sweden, but they vary in their topography and socioeconomic characteristics (Dribe and Bengtsson 1997). Hög, Kävlinge, and Sireköpinge were plain land farming regions (open farmlands) which in general focused on grain production. Kågeröd was a forest region with large forest areas; Halmstad a brushwood region with wooded areas in the north and plain lands in the south (Dribe, Olsson, and Svensson 2011). Moreover, Sireköpinge, Halmstad, and Kågeröd had primarily a manorial system in which tenants leased their farms for a certain period; in Hög and Kävlinge freeholders and crown-tenants were more common, who owned their land and paid taxes for it. Furthermore, Hög and Kävlinge underwent a major enclosure in 1804, in which most of the farmers moved out from their villages into their property units. Halmstad was enclosed in 1827 and 1844, Kågeröd in the period 1839–1842, and Sireköpinge in 1849. All parishes stayed rural and had a similar economic structure and development as well as population growth for the whole study period, except for parts of Kävlinge, which developed into an industrialized village from the 1890s.

Moreover, the soils within the study area are among the most fertile in Sweden, especially in the plain lands. Sweden is mainly dominated by postglacial soil till/moraine, and the most fertile soils are clayey till (clay content 5–15%) and clay-till (clay content 15% and above). Clay soils are also fertile in general, although clay content and topography have a big influence (Eriksson et al. 2005). For example, clay soils in low lands have an increased risk of becoming waterlogged (Bohman 2010). In addition, clay soils as well as clay-tills with high clay content are generally heavy to work with and require more plough animals than lighter soils. Sandy soils, on the other hand, require less labour, but they are also less fertile. The soil types of the areas considered in this study constitute approximately 25 detailed soil type classes (Figure 1). The dominant ones are variations of till: sandy till, clayey till, coarse clay-till (15–25% clay content), and fine clay-till (clay content above 25%). Various sand soils and clay soils are also quite common.

Figure 1: **Common soil types in: 1) Sireköpinge, Halmstad, and Kågeröd parishes; 2) Hög and Kävlinge parishes**
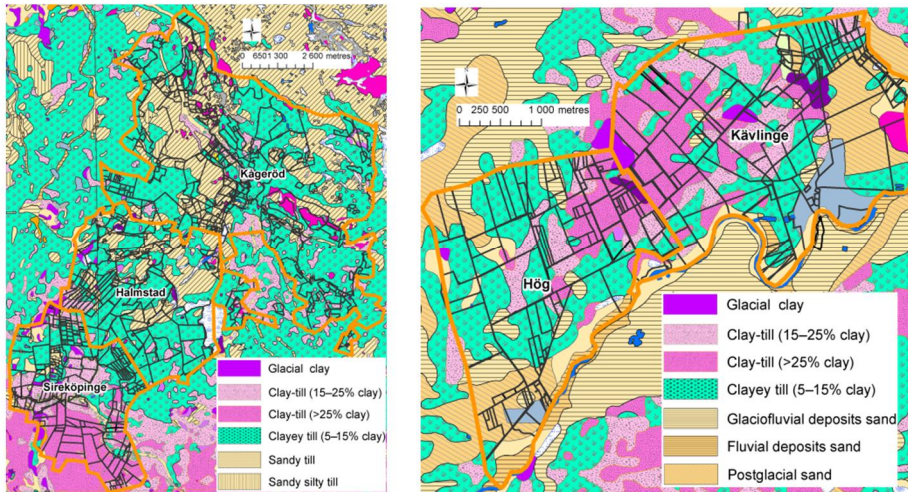
Notes: The legend shows only some of the most common soil types. The black lines represent property unit borders in 1910; the orange lines represent parish borders.
Source: SGU (2014).

4. Data

We use individual-level longitudinal data from the Scanian Economic Demographic Database (SEDD), created by the Centre for Economic Demography at Lund University, in collaboration with the Regional Archives in Lund (Bengtsson et al. 2014). The dataset for analysis was created using a programme developed by Quaranta (2015, 2016). The SEDD includes demographic and economic information on all inhabitants who have lived in the five parishes from 1646 to the present. In this study, we use a subset of the SEDD for the period 1850–1914. Note that we exclude the individuals living inside the urban area of Kävlinge parish because they were not likely to be affected by soil type. The database contains continuous information on family and household structure; dates of birth, marriages, and deaths; and dates of individuals' migration within and between parishes. Causes of death have also been registered from 1750 onwards. The primary sources for the SEDD are vital registers, catechetical examination registers/parish registers, and annual poll tax registers. The catechetical registers start from 1815, which means that the information about the household

structure and individual exposure to economic and demographic factors used in this study is well covered. Moreover, the data quality of births and infant deaths has been evaluated by estimating the birth sex ratio and the share of infant deaths occurring during the first months of life for different social groups (Bengtsson and Lundh 1994; Bengtsson and Dribe 2010).

In addition, we have information about the detailed geographic location of each of the individuals who have lived in the five parishes. In a recent study we have combined historical maps and demographic information from SEDD to link around 53,000 individuals in the five rural parishes, for the period 1813–1914, to the property units they lived in (Hedefalk 2016; Hedefalk, Harrie, and Svensson 2014, 2015; Hedefalk, Svensson, and Harrie 2017). The property units are stored in temporal representations of longitudinal object lifelines. That is, for each property unit we have yearly information about when it was created, reformed, and when it ceased to exist. This information is derived from cadastral dossiers and textual sources such as poll tax registers (Hedefalk, Harrie, and Svensson 2015). Consequently, we have information about the residential histories of individuals and the shapes of property units that was updated on an annual basis.

With regards to the quality of the geocoding, the linkage between the poll tax registers and the digitized property units has been carried out on two levels of detail: on the exact property unit and on the address level (when property units were subdivided or partitioned into smaller units, they did not receive new designations; thus, multiple close-by property units may share an address). For Kävlinge, Halmstad, Kågeröd, and Sireköpinge, 50% of the property units in the poll tax registers have been linked to the exact corresponding digitized property unit; for Hög parish, the link level is 85%. Moreover, 94% of the property units (all parishes) in the poll tax registers have been matched to a digitized property unit on the address level (Hedefalk, Harrie, and Svensson 2015). Soil type data on the exact property unit level is used when such linkage exists; otherwise, soil type data on the address level is used. Some individuals in the dataset used in this study, primarily poor and landless individuals, could not be linked to a property unit for a span of years, or for their whole lifetime. This amounted to 10.9% of the children's (aged 1–15) time at risk (c.f. Section 5.3). The positional accuracy of the digitized property units used in this study (i.e., the average distance between a property unit border in the dataset and its corresponding border in the true world) has a root mean square error (RMSE) of 17 metres (cf. Hedefalk, Svensson, and Harrie 2017).

We obtained the soil type data from the Swedish Geological Survey (SGU). The information builds on mappings and field surveys that began in the 1960s and is ongoing today (SGU 2014). We use this modern information because detailed historical maps of the soil types are not available for our study period and area; however, soil

types did not normally change in the demographic time scale of interest (SGU 2016). Common for all the data is that the observations are conducted at around half a metre's depth; i.e., under the food soil. For our study area, the soil types have been estimated through detailed fieldwork and the data quality is assumed to be homogenous across the regions (SGU 2014). The positional accuracy for the soil types used in this study is approximately 50–75 metres. Note also that the defined spatial boundaries of the soil types are often not sharp. Instead, they mark transition zones of the soil types (SGU 2014).

5. Methods

This study focuses on the period after the large land reforms had taken place in all of the five parishes; i.e., from 1850 to 1914. Before these enclosures, the effects of soil type were small for individuals within a parish. We begin at age 1 and consider children until they turn 15, which was when they usually left home (Dribe 2000). The main independent variable of interest considered is the soil type of the property units in which the children resided.

5.1 Variables used in the analyses

We control for various socioeconomic and family-level factors, which are explained in the following paragraphs.

Soil type coverage. We create a variable defining the soil type where the children resided by first computing the geometric intersection for each property unit and soil type (shown in Figure 1), and then estimating the percentage of spatial coverage for soil types. Lastly, individuals are linked through poll tax registers and other sources to the digitized property units that they have lived within (cf. Hedefalk, Harrie, and Svensson 2015). The soil type classes are thereafter aggregated into seven groups: water, rock, peat, clayey till (till with a clay content of 5–15%), clay-till/clay soils (including coarse and fine clay-till with clay content 15% and above), and sandy soils (including gravel and sandy till soils). Finally, we create one categorical variable based on the spatial coverage of the soil types, which consists of five variable groups: 50–75% spatial coverage of clayey till, 75–100% spatial coverage of clayey till, 50–100% spatial coverage of clay-till/clay soils, 50–100% spatial coverage of sandy soils, and mixed soils. The mixed soil type is the smallest group (cf. Table 2) and represents areas that do not have large proportions of any specific soil type. This group is primarily constituted of clayey till, sandy soils, and clay-till/clay soils. We split the clayey till

group into two categories, 50–75% and 75–100%, because of the large proportion of this soil in the study area (see Table 2). We expect that areas with large coverage of clayey till or clay-till/clay are more fertile than sandy soils. Additionally, the clayey till soils may have been less difficult to work with than the heavier clay-till/clay soils (Eriksson et al. 2005; Bohman 2010). Therefore, we expect that farmers' children who lived in property units with higher spatial coverage of clayey till experienced relatively lower mortality because of higher levels of nutrition. Because the mixed soil type group is heterogeneous, it is difficult to make assumptions about children living in areas covered by such soil.

Socioeconomic status (SES). This variable is based on the children's family's access to land and the ability to support themselves with that land (and whether they were able to employ labour or not); i.e., having land above subsistence level (cf. Bengtsson and Dribe 2010). Such ability was related to having a taxation value (Swedish *mantal*) higher than, or equal to, 1/32. Bengtsson and Dribe (2010) use a higher value, 1/16, but this value reflects the subsistence level in the first half of the 19th century and earlier. The Swedish taxation values remained static despite improvements in productivity. Thus, 1/32 is a more accurate limit of the subsistence level in the second half of the 19th century (cf. Svensson 2001: 66–67). We create the following four variable groups (Table 2).

1) Freeholders and crown tenants with land of at least subsistence level.

2) Noble tenants having time-limited leasing agreements on manorial lands above subsistence level.

3) Semilandless individuals, a group including freeholders, crown tenants, and noble tenants with land below the subsistence level, as well as crofters and cottagers with or without land similar in size.

4) Landless individuals, foremost soldiers, workers, and servants.

When constructing these groups, individuals belonging to the nobility and owners of large manors are excluded because they are too few in number to constitute their own group. Moreover, because of the structure of the poll tax registers, all individuals within the same family are assigned the same taxation value. This means that those servants and their children who belonged to the family that owned or leased the farm were assigned the taxation value of that farm. By contrast, children to servants who constituted their own household or family, who often lived in separate buildings, were classified according to the taxation value of their parent's property (commonly of zero value). Thus, we make the assumption that children to servants living within the same

family as the household head were in general better off than children to servants constituting their own household. (As a sensitivity test, we also estimated models where every servant was classified as landless, but the results did not change.)

Taxation value. This is a ratio (continuous) value used as a rudimentary estimation of the productivity of the farm, which in turn can be used as a measure of wealth of the individuals owning or leasing the farm.

Parish of residence, sex, and birth year.

SES v2. Because we expect soil to primarily affect the mortality of those dependent on their land for subsistence, we introduce a new measure of SES that categorizes the families into three groups based on taxation value and property unit area, but not on land type: large-scale farmers, small- and medium-scale farmers (henceforth called farmers), and labourers. As stated earlier, farmers constitute a group who owned properties that were large enough to provide them with at least the majority of the earnings needed to support themselves. Families having smaller and less productive lands than the farmers, including the landless, are defined as labourers. Lastly, the large-scale farmers constitute a small group of the wealthiest individuals. See Appendix 1 for a detailed description of the categorization of the variable groups. Concerning the relationship between the variables SES and SES v2, freeholders, tenants, and semilandless (with relatively large farms) individuals constitute the farmers, whereas semilandless (with relatively small farms) and landless individuals constitute the labourers (cf., Table 2).

Explanatory variables used for sensitivity tests. As a sensitivity analysis, we estimated models that also controlled for property unit area, population density, land type, and whether children lived in large demesnes/satellite units. Further details on these variables are provided in Appendix 2. It should be noted that the property unit area was positively correlated with the taxation value (0.407 for areas below 100 hectare), and additional models showed that taxation value was a more accurate predictor for child mortality than area. Therefore, we exclude property unit area from the main models, which instead consider taxation value.

5.2 Statistical analysis

We estimate different models that consider as outcome mortality of children aged 1–15 (Table 1). Control variables are introduced in a stepwise manner in order to observe changes in the effects by adding additional variables and to be able to compare the findings to previous results. The study focuses primarily on mortality from all causes as an outcome, but we run separate models that consider specifically death from airborne infectious diseases and from nonairborne infectious diseases as outcomes. We first

estimate simple models focusing on parish of residence and socioeconomic status. Thereafter, we extend these models with the inclusion of the soil type variable in order to study whether soil type may explain some of the previously found mortality differences between the parishes in our study area. Moreover, models 1b and 5b analyse the mortality risk from nonairborne/unspecified diseases in order to better identify deaths that could have been caused by the lack of nutrition, whereas models 1c and 5c analyse the mortality risk from only airborne diseases to identify deaths that could have been caused by increased exposure to highly virulent diseases (cf. Table 2).

Table 1:   Models considering outcome mortality of children aged 1–15

Model	Variables						
	Parish	SES	SES v2	Taxation value	Soil type	Birth year	Sex
1a All causes	x	x				x	x
1b Nonairborne	x	x				x	x
1c Airborne	x	x				x	x
2 All causes	x		x			x	x
3 All causes	x			x		x	x
4 All causes	x				x	x	x
5a All causes	x		x	x	x	x	x
5b Nonairborne	x		x	x	x	x	x
5c Airborne	x		x	x	x	x	x

Notes: Variables included in the models are marked by the letter x.

Likelihood Ratio (LR) tests on models 1a and 3–5a analyse whether the addition of variables in the extended models improve model fit. We run a separate model for infants as a sensitivity analysis to test if their mortality is affected by soil type.[3] Moreover, except for model 1b and 1c, the models are also estimated separately for children of labourers and small- and medium-scale farmers. For models 1a and 3–5a, Cox proportional hazard models are used (Therneau and Grambsch 2000), whereas a competing-risks regression model is used for models 1b-c and 5b-c (Fine and Gray 1999). All Cox proportional hazard models also included a shared frailty component to measure the proportion of unobserved characteristics shared between members of the same household. That is, thetas were obtained to measure within-household variation in

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[3] These models revealed no effects from parish of residence, social class, and soil type; however, the unlinked soil type group had a significantly higher hazard of death compared to the reference category clayey till 75–100%.

mortality. Because of the spatial autocorrelation[4] for the soil types, we also tested models with property units as a shared frailty (not reported here), but this did not change our results. Tests based on Schoenfeld residuals were conducted after each model to test the proportionality of the hazards, and no violations in this assumption were found in the main explanatory variables.

Because the studied age group of 1–15 years may be heterogeneous, as a sensitivity analysis we also studied separately the age groups 1–4 and 5–15. We first performed ANOVA tests, which revealed that there were no statistical significant differences in the causes of deaths of children of the two age groups (both for all children and for the two socioeconomic groups). We also estimated separate Cox proportional hazard models for the two age groups. Although the hazard ratios and p-values varied somewhat, the patterns remained consistent to results of the model that focused on children aged 1–15 (Tables 5–6, Model 5a). Finally, we observed a correlation between some of the soil type groups and parishes and, in some degree, between soil type and SES, which indicates a possible redundancy between the variables. There were also overlaps between parish and SES. That is, freeholders mainly resided in Hög, Kävlinge, and Kågeröd, whereas tenants commonly lived in Sireköpinge, Halmstad, and Kågeröd; the groups considered in the newly introduced measure of SES (SES v2), landless and semilandless, however, were more equally distributed among the parishes. We tested for multicollinearity by estimating linear regressions including soil and parish and thereafter checked the variance inflation factor (VIF). These tests showed no indication of such multicollinearity issues between the variables. Hence, the variables likely explain different parts of the variations in mortality in the model.

5.3 Descriptive statistics

Table 2 shows the distribution of the children's time at risk in percentage among the categorical variables considered in this study, and the average values of the continuous variables. The values for the taxation value represent only those individuals that had a value higher than zero. As seen in the table, farmers have a higher taxation value. The unlinked soil type group represents the share of individuals that for parts of, or for their whole life course, could not be linked to a property unit. These individuals belonged

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[4] Moran's *I*, a measure of spatial autocorrelation, was found to be only 0.05 for the detailed soil types covering the study area (Figure 1), but higher for the specified soil type variable group (Figures 2–3). For example, for the period 1900–1914, Moran's *I* was 0.29 (p-value: 0.00) for the whole study area, 0.30 (p-value: 0.00) for the region covering Kågeröd, Halmstad, and Sireköpinge, and 0.07 (p-value: 0.14)) for the region covering Kävlinge and Hög (Figures 2–3). The latter indicates an insignificant spatial autocorrelation for Hög and Kävlinge, which may be explained by their small area.

primarily to the landless class and some of them were the poorest people, who wandered about between farms and other lodgings. Consequently, it has been difficult to link them to a household or to a property unit.

Table 2: **Distribution of the time at risk in person-years on the independent variables used in this study, farmer and labourer children, age 1–15, Scania, 1850–1914**

	All	Small- and medium-scale farmers	Labourers
	%	%	%
Soil type			
Clayey till 75–100%	20.43	22.28	20.60
Clayey till 50–75%	20.21	23.38	19.99
Clay-till/clay 50–100%	21.81	29.20	19.69
Sandy soils 50–100%	17.10	15.24	17.43
Mixed	9.58	9.91	8.89
Unlinked	10.88		13.40
SES			
Freeholders	9.56	33.68	
Tenants	15.06	50.41	
Semilandless	18.10	15.91	20.22
Landless	57.28		79.78
SES v2			
Large farmers	6.90		
Small-medium farmers	21.13		
Labourers	71.98		
Parish			
Hög	9.16	15.14	7.21
Kävlinge	8.32	9.18	7.61
Halmstad	19.41	24.28	18.98
Sireköpinge	27.85	27.14	28.26
Kågeröd	32.25	24.26	37.94
Sex			
Female	47.92	48.03	48.11
Male	52.08	51.97	51.89
Birth year	1872.75	1871.43	1873.03
(average and min–max)	(1835–1912)	(1835–1912)	(1835–1912)
Taxation value	0.27	0.15	0.01
(average and min–max)	(0.01–3.00)	(0.02–0.4)	(0.00–0.03)
Individuals	15,485	3,235	12,900
Deaths	997	207	744

Table 3 shows 9 diagnostic categories of causes of death for the children in our study area. These groups have been created from 29 diagnostic groups (cf. Bengtsson and Lindstrom (2000) for a detailed description). All infectious diseases have been classified into three groups: airborne (e.g., smallpox, measles, scarlet fever, and whooping cough), foodborne and waterborne (e.g., nervous fever, typhoid fever, and dysentery), and others (e.g., blood poisoning, diarrhoea, and other unclassifiable diseases). Moreover, the group 'Other specified noninfectious diseases' includes

gastrointestinal diseases, psychiatric diagnoses, congenital heart disease, and kidney suffering. Table 3 shows that the largest groups of causes of death for both classes were the nonspecified diseases, followed by the airborne diseases. The share of causes of deaths is almost identical between the two groups. Some differences, however, are observed; e.g., the labourers' children have a higher share of accidents and crimes, as well as food- and waterborne diseases.

To create sufficiently large groups for the cause-specific models (presented in Tables 4–6), we study the mortality where the outcome is from either nonairborne/unspecified diseases or airborne diseases. Such classification has two limitations that may introduce biases in the analyses. First, the nonairborne/unspecified group is heterogeneous, with a very large share of cases not being specified. Second, diseases such as different types of respiratory infections, measles, and tuberculosis cause approximately half of the deaths within the group airborne infectious diseases, for which the risk of infection may be influenced by an individual's nutritional status (cf. e.g., Bellagio conference authors 1985). Therefore, we cannot estimate models for causes of deaths that are either explicitly linked to nutrition or not linked to nutrition (i.e., highly virulent diseases). Hence, the results from the cause-specific models have to be interpreted with care. Despite this limitation, analysing the mortality using such models is, nonetheless, a first step towards trying to better understand the influence of soil type, as an indicator of nutrition, on child mortality.

Table 3: **Mortality by cause of death, farmer and labourer children, age 1–15, Scania, 1850–1914. Total and relative frequencies**

	Small- and medium-scale farmers		Labourers	
	Total	%	Total	%
Airborne infectious diseases	61	29.47	221	29.70
Food- and waterborne infectious diseases	8	3.86	50	6.72
Other infectious diseases	2	0.97	4	0.54
Cardiovascular diseases and diabetes	2	0.97	9	1.21
Accidents, crimes, etc.	1	0.48	21	2.82
Cancer	1	0.48	5	0.67
Other specified noninfectious diseases	23	11.11	79	10.62
Not specified	109	52.66	355	47.72
Total nonairborne infectious diseases/not specified	146	70.53	523	70.30
Total	207	100	744	100

Figures 2 and 3 show the spatial distribution of the soil type groups for all children aged 1–15. Note that the maps show all the property units that ever existed during each 10-year period. This means that some property units may overlay each other on the map, and that some property units may have existed for only a short period. Moreover, the empty areas in white represent property units where no individuals are linked. The large white area in Kävlinge parish represents the urban area that we excluded in the analyses. As regards to the soil type distribution, clay-till/clay soils dominate in the middle of Kävlinge and Hög, as well as in the southern parts of Sireköpinge (mainly clay-tills). Halmstad and Kågeröd are dominated by areas with large proportions of clayey till and sandy soils. Note also that the soil type variable seems to change for some property units through time. This is because the property units change size (e.g., because of subdivisions) through time and that larger property units are sometimes overlaid by smaller property units in the map. Hence, although the soil type is static, the soil type variable sometimes varies in time.

Figure 2: **Distribution of the soil variable based on the % of the spatial coverage of soil types in each property unit in Hög and Kävlinge parishes**
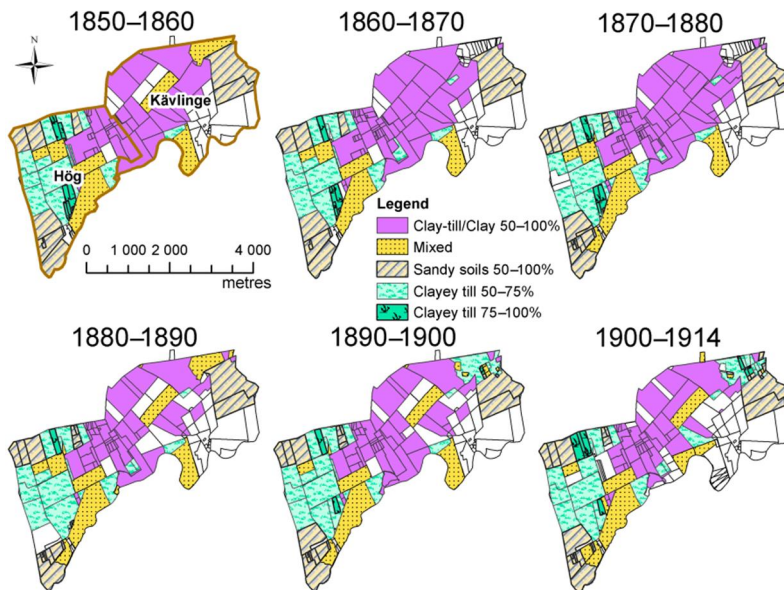
Note: The large white area in Kävlinge parish represents the urban area excluded in the analyses. Other white areas represent property units where no individuals (children aged 1–15) are linked.

Figure 3: **Distribution of the soil variable based on the % of the spatial coverage of soil types in each property unit in Sireköpinge, Halmstad, and Kågeröd parishes**
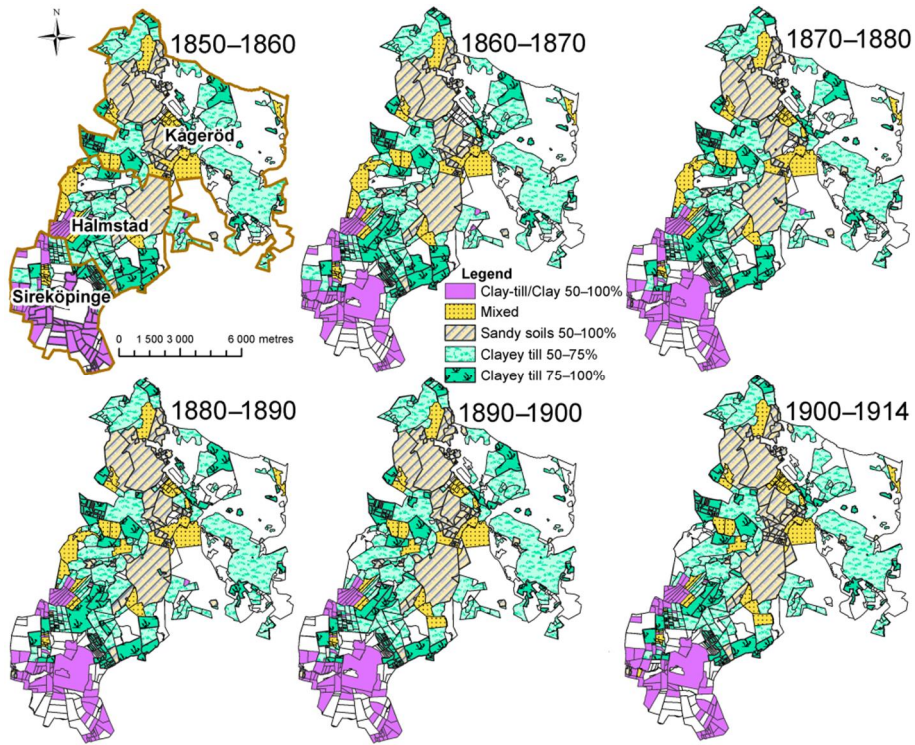
Note: The white areas represent property units where no individuals (children aged 1–15) are linked.

Figures 4a–d show the cumulative hazards of death for children aged 1–15 by SES, SES v2, parish of residence, and soil type. Large socioeconomic differences in mortality are observed in Figures 4a and b. Here, freeholders (Figure 4a) and large-scale farmers (Figure 4b) experience the lowest mortality. These mortality differences emerge also at an earlier age compared to the ones observed for parish of residence and soil type (Figures 4c–d). For the two groups studied separately in this paper (small- and medium-scale farmers, and labourers, in Figure 4b), there are small or nonexistant differences in mortality levels. Moreover, Figure 4c shows that children living in the semiurban parish Kävlinge experienced the highest cumulative hazard of death, whereas the lowest cumulative hazard of death was found for children living in

Kågeröd. Lastly, we observe mortality differences between the soil types groups, in which children living in property units with mixed soil types experience the lowest mortality, whereas the unlinked children have the highest risk of dying.

Figure 4: **Nelson–Aalen cumulative hazards by SES, SES v2, parish of residence, and soil type, ages 1–15, 1850–1914**
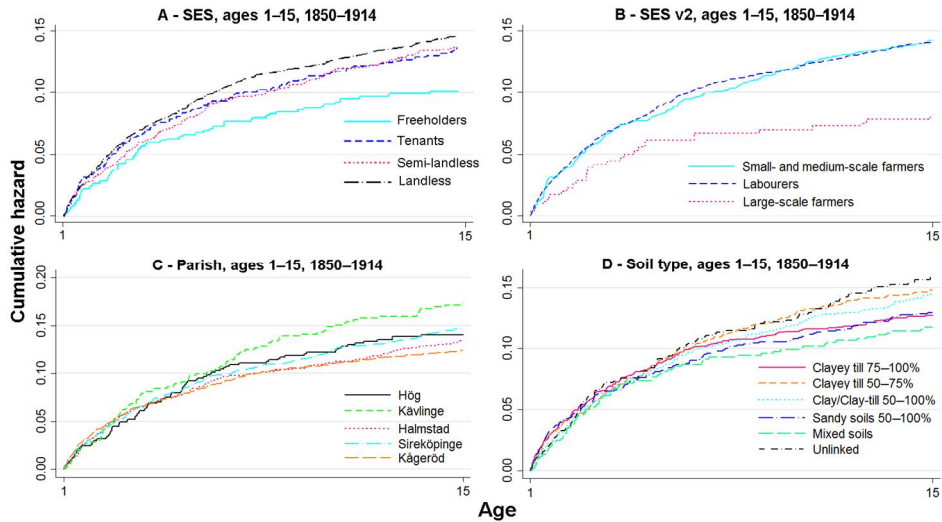
6. Results

Table 4 shows the results from the models estimated for all children aged 1–15. The only significant effect of soil type is found in the model that considers as outcome mortality from only airborne diseases (model 5c). Here, children living in areas covered by 50–75% clayey till experience a 58% higher mortality risk compared to the reference category. In this model, the unlinked group also experiences a significantly higher risk of death. Moreover, we find consistent effects from parish, as previous studies have shown (e.g., Bengtsson and Dribe 2010), also when controlling for the socioeconomic measures SES, SES v2, and taxation value. The magnitude of the effects and the statistical significance are, however, reduced for some of the parishes when introducing the socioeconomic measures in the models in a stepwise manner (not shown in this

paper). Large mortality differences between the nonairborne/unspecified and airborne diseases for the parishes are also observed (Models 1b–c and 5b–c).

The freeholders (when considering the first SES classification) and large-scale farmers (when considering the second SES classification) experience a relatively much lower risk of death compared to the other social groups. However, in the cause-specific models, this effect is only statistical significant in the models estimated for airborne diseases. Hence, these results may indicate that some of the airborne infectious diseases are nutrition-dependent, or that the upper classes were less exposed to highly virulent diseases. Moreover, year of birth had a beneficial effect on children: an increase of one in year of birth decreases the mortality risk by 1% (model 5a).

The results in Table 4 indicate that soil type may not be representative of the nutritional level of all children aged 1–15. Because we expect the effect of soil type to primarily affect farmers' children, we estimate separate models for the children to labourers and small- and medium-scale farmers. The large-scale farmers constitute a group too small to estimate separate models for them.

Table 4: Impact of soil type and other factors on mortality, Scania, 1850–1914. Children aged 1–15

| | \multicolumn{6}{c}{1 Parish-SES} | | | | | 2 Parish-SESv2 | | 3 Parish-Tax | |
| | \multicolumn{2}{c}{a All causes} | \multicolumn{2}{c}{b Nonairborne/ unspecified} | \multicolumn{2}{c}{c Airborne} | All causes | | All causes | |
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish										
Hög	1.31	0.05	1.39	0.03	1.04	0.86	1.12	0.39	1.13	0.37
Kävlinge	1.58	0.00	1.27	0.12	1.97	0.00	1.43	0.00	1.42	0.01
Halmstad	1.09	0.43	1.42	0.00	0.50	0.00	1.08	0.49	1.09	0.39
Sireköpinge	1.18	0.07	1.51	0.00	0.63	0.00	1.17	0.08	1.18	0.07
Kågeröd	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc
SES										
Freeholders	0.68	0.02	0.81	0.25	0.51	0.01				
Tenants	1.08	0.52	1.05	0.72	1.05	0.80				
Semilandless	1.00	rc	1.00	rc	1.00	rc				
Landless	1.16	0.12	1.18	0.11	1.07	0.67				
SES v2										
Large-scale farmer							0.65	0.01		
Small-medium farmer							0.98	0.81		
Labourer							1.00	rc		
Taxation value									0.85	0.17
Soil type										
Clayey till 75-100%										
Clayey till 50-75%										
Clay-till/clay 50-100%										
Sandy soils 50-100%										
Mixed										
Unlinked										
Birth year	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
Sex										
Female	1.00	rc	1.0	rc	1.00	rc	1.0	rc	1.00	rc
Male	1.05	0.43	1.02	0.78	1.07	0.56	1.05	0.44	1.05	0.46
theta	0.38	0					0.37	0	0.38	0
LR chi2	\multicolumn{2}{c}{14,896.11}	\multicolumn{2}{c}{48.67}	\multicolumn{2}{c}{81.84}	\multicolumn{2}{c}{15,031.44}	\multicolumn{2}{c}{14,904.27}
Prob>chi2	\multicolumn{2}{c}{0.00}	\multicolumn{2}{c}{0.00}	\multicolumn{2}{c}{0.00}	\multicolumn{2}{c}{0.00}	\multicolumn{2}{c}{0.00}
Subjects	\multicolumn{2}{c}{15,485}	\multicolumn{2}{c}{15,485}	\multicolumn{2}{c}{15,485}	\multicolumn{2}{c}{15,485}	\multicolumn{2}{c}{15,485}
Deaths	\multicolumn{2}{c}{997}	\multicolumn{2}{c}{703}	\multicolumn{2}{c}{294}	\multicolumn{2}{c}{997}	\multicolumn{2}{c}{997}
Competing			\multicolumn{2}{c}{294}	\multicolumn{2}{c}{703}				

Notes: HR = hazard ratio, rc =reference category, person-years at risk: 96,952.

Table 4:   (Continued)

|	4 Parish-Soil		5 Parish-Soil-SESv2-Tax					
	All causes		a All causes		b Nonairb./ unspecified		c Airborne	
	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish								
Hög	1.17	0.26	1.16	0.27	1.28	0.10	0.88	0.56
Kävlinge	1.43	0.01	1.42	0.01	1.23	0.20	1.67	0.01
Halmstad	1.13	0.27	1.11	0.32	1.45	0.00	0.51	0.00
Sireköpinge	1.23	0.05	1.22	0.06	1.56	0.00	0.66	0.02
Kågeröd	1.00	rc	1.00	rc	1.00	rc	1.00	rc
SES								
Freeholders								
Tenants								
Semilandless								
Landless								
SES v2								
Large-scale farmer			0.62	0.01	0.78	0.24	0.44	0.02
Small-medium farmer			0.99	0.89	1.00	0.96	1.01	0.95
Labourer			1.00	rc	1.00	rc	1.00	rc
Taxation value			1.07	0.64	0.85	0.27	1.35	0.20
Soil type								
Clayey till 75-100%	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Clayey till 50-75%	1.20	0.10	1.20	0.10	1.05	0.68	1.58	0.02
Clay-till/clay 50-100%	1.04	0.77	1.04	0.74	0.95	0.69	1.23	0.35
Sandy soils 50-100%	1.09	0.48	1.10	0.45	1.08	0.55	1.21	0.39
Mixed	0.91	0.52	0.91	0.54	0.79	0.15	1.35	0.23
Unlinked	1.23	0.11	1.28	0.07	1.04	0.77	1.62	0.04
Birth year	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00
Sex								
Female	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Male	1.05	0.45	1.05	0.42	1.02	0.80	1.08	0.53
theta	0.40		0.40					
LR chi2	14,721.67		14,894.24		49.37		88.93	
Prob>chi2	0.00		0.00		0.00		0.00	
Subjects	15,485		15,485		15,485		15,485	
Deaths	997		997		703		294	
Competing					294		703	

Notes: HR = hazard ratio, rc =reference category, person-years at risk: 96,952.

Table 5 and Figure 5 show the results from the separate models for children to small- and medium-scale farmers. (Note: Figure 5 shows only the effects from the soil type and parish variables.) A relatively strong effect of soil types and taxation value on mortality is revealed, which is consistent across the models.[5] Thus, the results indicate a possible effect of nutrition, through soil type and taxation value, on the mortality of the

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[5] Although the property unit area was not included in the models because of its correlation with taxation value, as a sensitivity analysis, we estimated models that included area instead of taxation value, as well as models including both variables. Models including population density were also estimated. In all of these models, the effect of soil type remains.

farmers' children. Moreover, we observe no significant mortality differences between the parishes for this group of children. However, in the cause-specific model for nonairborne/unspecified diseases (model 5b), children residing in Halmstad and Sireköpinge show higher hazards of death. Overall, children residing in areas with very high proportions of clayey till (75–100% coverage) experience a lower risk of dying compared to children residing in areas with other soil types. In particular, children residing in property units with a spatial coverage of 50–75% clayey till or with mixed soils have approximately twice as high a hazard of death as children residing in property units with a spatial coverage of 75–100% clayey till (models 4 and 5a). The magnitude of the effects, as well as the statistical significance, of the soil types decreases in the model that considers as outcome mortality from nonairborne or unspecified diseases (model 5b), although the pattern of the effects remains constant. An exception is the effects of the group sandy soils 50–100%, for which the effect becomes stronger and statistically significant at the 5% level. That is, the hazard of death from nonairborne/unspecified diseases for children residing in farms with soil type sandy soils 50–100% is 96% higher relative to children living in farms with soil type clayey till 75–100%. Thus, in this cause-specific model we can observe a trend from lower hazards of mortality for children living in areas with large proportions of fertile clayey till soils to higher hazards of mortality for children living in areas with less fertile sandy soils.

Figure 5: **Impact of soil type and parish on child mortality, Scania, 1850–1914. Small- and medium-scale farmers, aged 1–15**
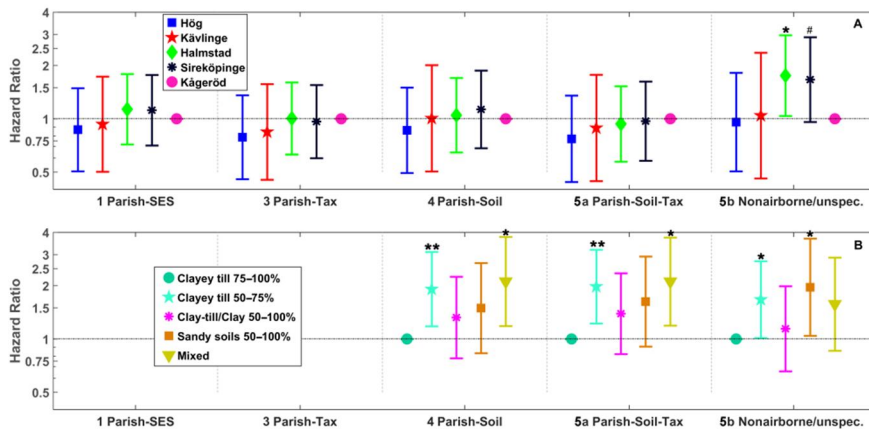
Notes: The estimates are taken from the models in Table 5. Note that the hazard ratios and their 95% confidence intervals (the bars) are plotted on a log scale. The asterisks and hashes on top of the bars denote the significance values. ***: p ≤ 0.001, **: p ≤ 0.01, *: p ≤ 0.05, #: p ≤ 0.1.

Table 5: **Impact of soil type and other factors on child mortality, Scania, 1850–1914. Small- and medium-scale farmers, aged 1–15**

| | 1 Parish-SES | | 3 Parish-Tax | | 4 Parish-Soil | | 5 Parish-Soil-Tax | | | |
| | All causes | | All causes | | All causes | | a All causes | | b Nonairborne/ unspecified | |
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish										
Hög	0.87	0.61	0.79	0.39	0.86	0.60	0.77	0.36	0.96	0.90
Kävlinge	0.93	0.82	0.84	0.59	1.01	0.99	0.89	0.74	1.04	0.92
Halmstad	1.13	0.60	1.01	0.98	1.05	0.85	0.94	0.79	1.75	0.04
Sireköpinge	1.12	0.63	0.96	0.88	1.13	0.64	0.97	0.91	1.66	0.07
Kågeröd	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Taxation value			0.18	0.05			0.16	0.04	0.23	0.11
Soil type										
Clayey till 75-100%					1.00	rc	1.00	rc	1.00	rc
Clayey till 50-75%					1.91	0.01	1.98	0.01	1.67	0.04
Clay-till/clay 50-100%					1.32	0.30	1.39	0.22	1.14	0.64
Sandy soils 50-100%					1.49	0.18	1.63	0.10	1.96	0.04
Mixed					2.11	0.01	2.11	0.01	1.57	0.14
Unlinked										
Birth year	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.98	0.00
Sex										
Female	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Male	1.28	0.09	1.28	0.09	1.29	0.08	1.29	0.08	1.21	0.26
theta	0.71	0.00	0.65	0.00	0.61	0.00	0.54	0.00		
LR chi2	2,855.50		2,926.66		2,906.05		2,989.27		29.34	
Prob>chi2	0.00		0.00		0.00		0.00		0.00	
Subjects					3,235				3,235	
Deaths					207				146	
Competing									61	
Person-years at risk					20,485				20,485	

*Note:* HR = hazard ratio, rc =reference category

Whereas the effect of the taxation value on mortality may seem relatively large, it represents the increase of 1 *mantal*, which is a large unit increase (the small- and medium-scale farmers have a *mantal* between 0.02 and 0.4). An increase of 0.1 of a *mantal* decreases the mortality risk by 8.4% (model 5a). Moreover, male children had a higher mortality risk compared to female children (e.g., 28.8% in model 5a) (P<0.1), and the shared frailty within the households was high: 53.9% in the model including soil type and taxation value (model 5a).

For the labourers' children, we observe no significant mortality differences between the soil type groups representing areas covered by high proportions of a specific soil type (Figure 6, Table 6).[6] Also, no beneficial effect of taxation value is

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[6] As a sensitivity analysis, we also included possible measures of disease indicators for the labourers' children: population density, area, and whether they resided in large satellite units or demesnes (results not shown). No significant effects on mortality of these variables were found.

found. However, labourers' children residing in areas with mixed soils (foremost a mix of clayey till, clay/clay-till, and sandy soils) experience in general a lower risk of dying compared to children residing in areas with other soil type groups. Moreover, the mortality differences observed in Figure 6 and Table 6 between the parishes for the labourers' children (model 1) are similar to the ones found in Table 4. This adheres to both the parish differences found for all-cause mortality as well as the large differences between the cause-specific models estimated for nonairborne/unspecified and airborne diseases. Note, however, that when including the soil type variable in the models considering all-cause mortality, there are no longer any statistically significant effects from Sireköpinge parish. Moreover, even though the urban area of Kävlinge was excluded in the analyses, children living in Kävlinge parish have a significantly higher mortality compared to the reference category in all models, except for the cause-specific model for nonairborne/unspecified diseases. This indicates that children also living outside the urban area in Kävlinge have an increased hazard of death from airborne diseases. Finally, the shared frailty within the households was generally smaller compared to the farmers' children: between 33.6% and 35.3% (Table 6: models 1, 3–4, 5a).

Figure 6: **Impact of soil type and parish on child mortality, Scania, 1850–1914. Labourers, aged 1–15**
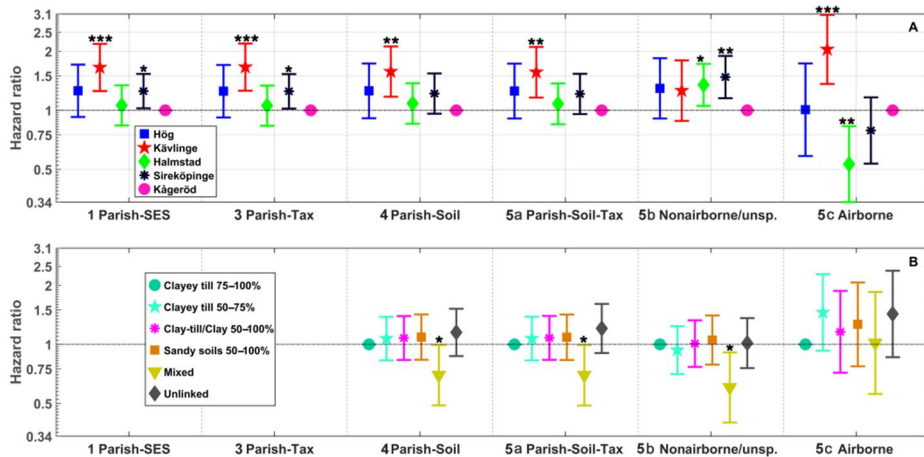
Notes: The estimates are taken from the models in Table 6. Note that the hazard ratios and their 95% confidence intervals (the bars) are plotted on a log scale. The asterisks and hashes on top of the bars denote the significance values. ***: p ≤ 0.001, **: p ≤ 0.01, *: p ≤ 0.05, #: p ≤ 0.1

Table 6: **Impact of soil type and other factors on child mortality, Scania, 1850–1914. Labourers, aged 1–15**

| | 1 Parish-SES | | 3 Parish-Tax | | 4 Parish-Soil | | 5 Parish-Soil-Tax | | | | | |
| | All causes | | All causes | | All causes | | a All causes | | b Nonairborne/ unspecified | | c Airborne | |
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish												
Hög	1.26	0.14	1.25	0.15	1.26	0.16	1.26	0.17	1.30	0.15	1.01	0.98
Kävlinge	1.66	0.00	1.66	0.00	1.58	0.00	1.57	0.00	1.26	0.20	2.05	0.00
Halmstad	1.06	0.63	1.06	0.65	1.08	0.51	1.08	0.53	1.35	0.02	0.53	0.01
Sireköpinge	1.25	0.03	1.25	0.03	1.22	0.10	1.21	0.11	1.48	0.00	0.79	0.23
Kågeröd	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Taxation value			1.15	0.40			1.24	0.23	0.91	0.55	1.77	0.08
Soil type												
Clayey till 75-100%					1.00	rc	1.00	rc	1.00	rc	1.00	rc
Clayey till 50-75%					1.07	0.61	1.07	0.60	0.94	0.64	1.46	0.10
Clay-till/clay 50-100%					1.08	0.57	1.08	0.56	1.01	0.95	1.16	0.55
Sandy soils 50-100%					1.09	0.53	1.09	0.54	1.05	0.73	1.27	0.35
Mixed					0.70	0.05	0.70	0.05	0.60	0.02	1.02	0.96
Unlinked					1.15	0.32	1.21	0.20	1.02	0.92	1.43	0.17
Birth year	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.99	0.00	0.98	0.08
Sex												
Female	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc	1.00	rc
Male	0.99	0.88	0.99	0.89	0.99	0.91	0.99	0.92	0.97	0.68	1.00	0.99
theta	0.34	0.00	0.35	0.00	0.34	0.00	0.35	0.00				
LR chi2	11,255.68		11,240.97		11,201.69		11,155.59		33.65		66.75	
Prob>chi2	0.00		0.00		0.00		0.00		0.00		0.00	
Subjects				12,900					12,900		12,900	
Deaths				744					523		221	
Competing									221		523	
Person-years at risk				69,782					69,782		69,782	

Notes: HR = hazard ratio, rc =reference category

Moreover, in Table 6 the model focusing on mortality from airborne diseases (model 5c) shows a higher risk of death for children living in areas with 50–75% clayey till, although such effect is just above the level for statistical significance (p=0.102).

7. Discussion and conclusions

By combining detailed geographic information on residential histories with information on soil type for each property unit, we were able to analyse the impacts of soil type on child mortality (ages 1–15) for the period 1850–1914. The results indicate that soil type primarily affected the mortality of the children of farmers. Particularly, these children experienced relatively lower mortality when living in property units covered by very high proportions of clayey till. We observed some effects of soil type for the labourers' children; however, in contrast to the farmers' children, they had a lower mortality when residing in property units covered by mixed soils (foremost constituted of clayey till, clay-till/clay, and sandy soils). This soil type, however, is a small heterogeneous category that may possibly correlate with other unobserved factors that are not considered in the models. Therefore, the results indicate some support for our first hypothesis; i.e., that soil type is a measure for nutrition of children of farmers. That is, certain soil types may have influenced the farm-level production pattern and the quantity and quality of the output, which in turn affected the nutritional level of the farmers' children and thus their likelihood of dying. Moreover, we found little support for our second hypothesis, which predicted that soil was instead a measure of exposure to virulent diseases, because soil types did not affect the mortality of the two groups equally. Consequently, the results indicate the relatively important role of nutrition as a mortality predictor for the farmers' children, which is in line with previous research on the link between nutrition and disease outcomes in preindustrial societies (e.g., McKeown 1976; Fogel 1994, 2004; Puleston and Tuljapurkar 2008; Floud et al. 2011). Note, however, that we have not been able to estimate models that explicitly describe diseases that are either dependent or not dependent on nutrition. In addition, the group containing the farmers' children is small. Therefore, the results of this study have to be interpreted with care and further research is needed to better study the relationship between nutrition and the risk of dying in a preindustrial society.

We expected that nutrition could explain some of the geographic differences in child mortality that had previously been found in the study area of this paper (Bengtsson 2004; Bengtsson and Dribe 2010). When estimating separate models by socioeconomic status, however, we only observed such geographic differences for the labourers' children, and they were present also after including soil types in the models. For these children, the parish differences in the risk of death from nonairborne/unspecified diseases were strikingly different from the parish differences in the risk of death from airborne infectious diseases. Thus, the results indicate that other unobserved factors, which we did not consider in this study, likely affected the labourers' children and caused the geographic mortality differences. Hence, further research is required for this child group.

A possible explanation for the different effects of soil on mortality for the farmers' children is that clayey till was in general more fertile than sandy soils and more manageable than heavy clay-till and clay soils. For example, in the cause-specific model for nonairborne/unspecified diseases, a trend can be observed from lower risks of mortality for children living in farms with more fertile soils (clayey till) to higher risks of mortality for children living in farms with less fertile soils (sandy soils). However, market and technological developments likely affected the suitability of a soil type for agriculture. Some soils may have been more suited for specific crops, which was likely influenced by the current market demand for these crops. For example, the rising popularity of new crops such as sugar beets, which began to be cultivated in the 1890s in the five parishes (BiSOS 1892), as well as the increased use of both natural and artificial fertilizers (Morell 2011) probably influenced the importance of some soil types. For example, well-drained medium to slightly fine-textured soils are good soils for sugar beets (FAO 2015). Hence, lands with large proportions of clayey tills and, possibly, clay-tills may have been suited for such crops. However, sugar beets are also sensitive to the pH value in the soil, which may vary across areas regardless of the soil type (FAO 2015). Moreover, the agricultural suitability of heavy clay soils may have increased in the latter part of our study period because of the improvements in drainage and the use of better tools (Morell 2011; Bohman 2010). To study the impact of such technological developments, we could have divided the analysis into two periods; however, this was not possible because it resulted in an insufficient sample size. Lastly, the shared frailty component, which measures unobserved characteristics within the household-level, was high in the models estimated for the farmers' children (54%). This suggests that their mortality is affected also by other unobserved factors that have not been considered in this study.

Moreover, the fertility of the soil as well as the animals and tools used on the farm likely affected the human workforce needed to cultivate the land. In addition to influencing agricultural productivity, such factors could have affected the level of human contact and thus exposure to virulent diseases. These factors may also correlate with socioeconomic status (e.g., the economic ability to own farm animals). Therefore, if soil type was a measure of exposure to virulent diseases, it may not necessarily affect the mortality of all social groups equally, as stated in the second hypothesis. Additionally, at farms with livestock production, parts of the agricultural output would likely be directed for animal feeding, which may have affected the diet of the people living at the farm. Lastly, the presence of livestock can also reduce exposure (inside the living areas) to some mosquito species transmitting malaria (Mayagaya et al. 2015). Thus, by including farm-level information on animal workforce in the models, we would be able to better study the abovementioned relationships. However, this has not been possible because of the lack of farm-level data on livestock.

Some research indicates that soil affects infant mortality; e.g., Munro et al. (1997) found that wards dominated by wet soils had a relatively high infant mortality. In contrast, we found no effect of soil types on mortality for infants in the models that we conducted as a sensitivity analysis. However, both the demographic and geographic data used in the study by Munro et al. (1997) were on an aggregate level, whereas this study uses longitudinal microlevel data over a smaller area. Furthermore, we did not classify the soils based on their wetness; therefore, the results may not be comparable.

Although this work brings new knowledge to our understanding of mortality in the past, it is not free from limitations. One such limitation concerns the individuals that for parts of or for their whole life-course have not been linked to a property unit. Many of the poorest families belonged to this group, families with no fixed addresses and who often resided in poorhouses. They were a vulnerable group with relatively high mortality (Table 4). Such individuals are important to consider in the analyses to avoid creating a potential risk of a bias in the results. Including them as a separate group (unlinked) in the soil type variable was one way to handle this problem. However, this was only possible in the less extended models for the labourers' children.

Another limitation is the correlation that exists between some of the soil type groups and parishes (see Figures 2–3) and, to some degree, between soil type and SES. Thus, there is some redundancy between the variables. The multicollinearity tests, however, showed no serious indications of such concerns; therefore, the variables likely explain different parts of the variations in mortality in the model. Connected to this issue is also the spatial autocorrelation of the soil types. To overcome such limitation, we estimated models that included a frailty component for a geographical unit; i.e., the property units (not shown in this paper). This did not change our main results in any substantial way. However, a more proper way to study this would be to use a model that also takes into account the neighbouring areas and thus controls for the spatial autocorrelation; for example, a Cox proportional hazard model with spatially shared frailties (Darmofal 2009).

A third limitation regards the quality of the soil type variable. The positional accuracy of the soil type data is between 50 to 75 metres, and the absolute positional accuracy of the digitized property units is approximately 17 metres (i.e., the average distance between a point in the dataset and its corresponding point in the real world). Moreover, some individuals who owned several property units were only linked to the property unit in which they lived, which means that the soil type and property unit area measures do not represent the size of the total land for these individuals. Thus, these uncertainties may introduce biases and errors in the models used in this study, e.g., by overestimating or underestimating the effects on mortality from soil, especially if the errors are nonrandom (see e.g., Zandbergen 2007; Hedefalk et al. 2016). Therefore, in future studies it is important to study the propagation of the uncertainty.

Moreover, the models on cause-specific mortality were limited by the large share of unspecified deaths and by the fact that the two groups considered, nonairborne/unspecified and airborne, may not necessarily represent a proper distinction between causes of death that may and may not be related to nutrition. However, we see these estimations as a first and preliminary step to better understand the role of nutrition on mortality. Further research that looks in more depth into different causes of death is required.

Lastly, the findings of this work could be extended by making some additional improvements to the models. Foremost it is possible to use various soil assessment models or specific crop yield models to more accurately estimate farm-level productivity (e.g., Brunt 2004; Steduto et al. 2009). In these models, we could include information such as detailed elevation data and topographic wetness indexes (TWI).

Despite the abovementioned limitations, this is, to our knowledge, the first longitudinal study at the microlevel that analyses the effects of soil type on mortality in a historical rural society, and we therefore contribute to the literature on the role of nutrition on the risk of dying in a preindustrial society.

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References

Abrahams, P.W. (2002). Soils: Their implications to human health. *Science of the Total Environment* 291(1–3): 1–32. doi:10.1016/S0048-9697(01)01102-0.

Allen, R.C. (2008). The nitrogen hypothesis and the English agricultural revolution: A biological analysis. *Journal of Economic History* 68(1): 182–210. doi:10.1017/S0022050708000065.

Bellagio conference authors (1985). The relationship of nutrition, disease and social conditions: A graphical presentation. In Rotberg, R. and Rabb, T. (eds.). *Hunger and history. The impact of changing food production and consumption patterns on society*. New York: Cambridge University Press: 304–308.

Bengtsson, T. (1999). The vulnerable child. Economic insecurity and child mortality in pre-industrial Sweden: A case study of Västanfors, 1757–1850. *European Journal of Population* 15(2): 117–151.

Bengtsson, T. (2004). Mortality and social class in four Scanian parishes, 1766–1865. In: Bengtsson, T., Campbell, C., and Lee, J.Z. (eds.). *Life under pressure: Mortality and living standards in Europe and Asia, 1700–1900*. London: MIT Press: 135–171.

Bengtsson, T. and Broström, G. (2010). Mortality crises in rural southern Sweden 1766–1860. In: Kurosu, S., Bengtsson, T., and Campbell, C. (eds) *Demographic responses to economic and environmental crises*. Kashiwa: Reitaku University Press: 1–16.

Bengtsson, T. and Dribe, M. (2010). Quantifying the family frailty effect in infant and child mortality by using Median Hazard Ratio (MHR). *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 43(1): 15–27.

Bengtsson, T. and Dribe, M. (2011). The late emergence of socioeconomic mortality differentials: A micro-level study of adult mortality in southern Sweden, 1815–1968. *Explorations in Economic History* 48(3): 389–400. doi:10.1016/j.eeh.2011.05.005.

Bengtsson, T., Dribe, M., Quaranta, L., and Svensson, P. (2014). *The Scanian Economic Demographic Database, Version 4.0*. Lund: Lund University, Centre for Economic Demography and Department of Economic History.

Bengtsson, T. and Lindstrom, M. (2000). Childhood misery and disease in later life: The effects on mortality in old age of hazards experienced in early life, southern Sweden, 1760–1894. *Population Studies* 54(3): 263–277. doi:10.1080/713779096.

Bengtsson, T. and Lundh, C. (1994). La mortalité infantile et post-infantile dans les pays Nordiques avant 1900. *Annales de Démographie Historique* 1994(1): 23–43.

Bengtsson, T. and van Poppel, F. (2011). Socioeconomic inequalities in death from past to present: An introduction. *Explorations in Economic History* 48(3): 343–356.

BiSos (1892). Bidrag till Sveriges officiella statistik. N, Jordbruk och boskapsskötsel. Stockholm: Statistiska centralbyrån, P.A. Norstedt & söner.

Bohman, M. (2010). Bonden, bygden och bördigheten: Produktionsmönster och utvecklingsvägar under jordbruksomvandlingen i Skåne ca 1700–1870. [PhD thesis]. Lund: Lund University, Department of Economic History.

Brändström, A. (1984). "De kärlekslösa mödrarna": Spädbarnsdödligheten i Sverige under 1800-talet med särskild hänsyn till Nedertorneå. [PhD thesis]. Umeå: Umeå University.

Brändström, A., Edvinsson, S., and Rogers, J. (2002). Illegitimacy, infant feeding practices and infant survival in Sweden, 1750–1950: A regional analysis. *Hygiea Internationalis* 3(1): 13–52. doi:10.3384/hygiea.1403-8668.023113.

Brunt, L. (2004). Nature or nurture? Explaining English wheat yields in the industrial revolution, c. 1770. *Journal of Economic History* 64(1): 193–225. doi:10.1017/S0022050704002657.

Claësson, O. (2009). Geographical differences in infant and child mortality during the initial mortality decline: Evidence from southern Sweden, 1749–1830. [Lic. thesis]. Lund: Lund University, Department of Economic History.

Darmofal, D. (2009). Bayesian spatial survival models for political event processes. *American Journal of Political Science* 53(1): 241–257. doi:10.1111/j.1540-5907.2008.00368.x.

Dobson, M.J. (1994). Malaria in England: A geographical and historical perspective. *Parassitologia* 36(1–2): 35–60.

Doran, J.W. and Parkin, T.B. (1994). Defining and assessing soil quality. *Defining Soil Quality for a Sustainable Environment* 35: 3–21.

Dribe, M. (2000). Leaving home in a peasant society. Economic fluctuations, household dynamics and youth migration in southern Sweden, 1829–1866. [PhD thesis]. Lund: Lund University, Department of Economic History.

Dribe, M. and Bengtsson, T. (1997). Economy and demography in western Scania, Sweden, 1650–1900. Kyoto: International research center for Japanese studies *(EAP working series paper no.10).*

Dribe, M., Olsson, M., and Svensson, P. (2011). *Production, prices and mortality: Demographic response to economic hardship in rural Sweden, 1750–1860.* Paper presented at the meetings of the European Historical Economics Society, Dublin, Ireland, September 2–3, 2011.

Eriksson, J., Nilsson, I., Simonsson, M., and Wiklander, L. (2005). *Wiklanders marklära*. Lund: Studentlitteratur.

Food and Agriculture Organization of the United Nations (FAO) (2015). Crop Water Information: Sugarbeet [electronic resource]. Rome: FAO Water Development and Management Unit. http://www.fao.org/nr/water/cropinfo_sugarbeet.html

Fine, J.P. and Gray, R.J. (1999). A proportional hazards model for the subdistribution of a competing risk. *Journal of the American statistical association* 94(446): 496–509. doi:10.1080/01621459.1999.10474144.

Fischer, G., van Velthuizen, H.T., Shah, M.M., and Nachtergaele, F.O. (2002). Global agro-ecological assessment for agriculture in the 21st century: Methodology and results. Laxenburg: IIASA: 157 pp.

Floud, R., Fogel, R.W., Harris, B., and Hong, S.C. (2011). *The changing body: Health, nutrition, and human development in the western world since 1700*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511975912.

Fogel, R. (1994). Economic growth, population theory and physiology: The bearing of long-term processes on the making of economic policy. *American Economic Review* 84(3): 369–395. doi:10.3386/w4638.

Fogel, R. (2004). *The escape from hunger and premature death, 1700–2100: Europe, America and the Third World*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511817649.

Fridlizius, G. (1984). The mortality decline in the first phase of the demographic transition: Swedish experiences. In Bengtsson, T., Fridlizius, G., and Ohlsson, R. (eds.). *Pre-industrial population change: The mortality decline and short-term population movements*. Stockholm: Almquist and Wiksell: 41–69.

Gadd, C.-J. (1983). Järn och potatis: Jordbruk, teknik och social omvandling i Skaraborgs län 1750–1860. [PhD thesis]. Göteborg: University of Gothenborg, Department of Economic History.

Gadd, C.-J. (2011). *The agricultural revolution in Sweden, 1700–1870.* Lund: Nordic Academic Press.

Goldstein, E.J.C., Katona, P., and Katona-Apte, J. (2008). The interaction between nutrition and infection. *Clinical Infectious Diseases* 46(10): 1582–1588. doi:10.1086/587658.

Gregory, I.N. (2008). Different places, different stories: Infant mortality decline in England and Wales, 1851–1911. *Annals of the Association of American Geographers* 98(4): 773–794. doi:10.1080/00045600802224406.

Hawley, J.K. (1985). Assessment of health risk from exposure to contaminated soil. *Risk Analysis* 5(4): 289–302. doi:10.1111/j.1539-6924.1985.tb00185.x.

Hedefalk, F. (2016). Life paths through space and time: Adding the micro-level geographic context to longitudinal historical demographic research. [PhD thesis]. Lund: Lund University, Department of Physical Geography and Ecosystem Science.

Hedefalk, F., Harrie, L., and Svensson, P. (2014). Extending the Intermediate Data Structure (IDS) for longitudinal historical databases to include geographic data. *Historical Life Course Studies* 1: 27–46.

Hedefalk, F., Harrie, L., and Svensson, P. (2015). Methods to create a longitudinal integrated demographic and geographic database on the micro-level. A case study of five Swedish rural parishes, 1813–1914. *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 48(3): 153–173. doi:10.1080/01615440.2015.1016645.

Hedefalk, F., Pantazatou, K., Quaranta, L., and Harrie, L. (2016). Importance of the geocoding level for historical demographic analyses: A case study of rural parishes in Sweden, 1850–1914. Lund: Lund University, Department of Physical Geography and Ecosystem Science, and Centre for Economic Demography.

Hedefalk, F., Svensson, P., and Harrie, L. (2017). Spatiotemporal historical datasets at micro-level for geocoded individuals in five Swedish parishes, 1813–1914. *Scientific Data* 4(170046).

Jaenicke, E. and Lengnick, L. (1997). A soil–quality index and its relationship to efficiency and productivity growth measures: Two decompositions. *American Journal of Agricultural Economics* 79(5): 1702–1702.

Kintner, H.J. (1985). Trends and regional differences in breastfeeding in Germany from 1871 to 1937. *Journal of Family History* 10(2): 163–182. doi:10.1177/036319908501000203.

Lazuka, V., Quaranta, L., and Bengtsson, T. (2016). Fighting infectious disease: Evidence from Sweden, 1870–1940. *Population and Development Review* 42(1): 27–52. doi:10.1111/j.1728-4457.2016.00108.x.

Lee, C.T. and Tuljapurkar, S. (2008). Population and prehistory I: Food-dependent population growth in constant environments. *Theoretical Population Biology* 73(4): 473–482. doi:10.1016/j.tpb.2008.03.001.

Lindgren, E. and Jaenson, T.G. (2006). Fästing-och myggöverförda infektionssjukdomar i ett kommande, varmare klimat i Sverige. *Ent. Tidskr* 127: 21–30.

Lundh, C. and Olsson, M. (2011). Contract-workers in Swedish agriculture, c. 1890s–930s: A comparative study of standard of living and social status. *Scandinavian Journal of History* 36(3): 298–323. doi:10.1080/03468755.2011.582620.

Mayagaya, V.S., Nkwengulila, G., Lyimo, I.N., Kihonda, J., Mtambala, H., Ngonyani, H., Russel, L.T., and Ferguson, H.M. (2015). The impact of livestock on the abundance, resting behaviour and sporozoite rate of malaria vectors in southern Tanzania. *Malaria Journal* 14(17): 1–13. doi:10.1186/s12936-014-0536-8.

McKeown, T. (1976). *The modern rise of population*. London: Arnold.

McKeown, T., Brown, R.G., and Record, R.G. (1972). An interpretation of the modern rise of population in Europe. *Population Studies* 26: 345–382. doi:10.2307/2173815.

Morell, M. (2011). Agriculture in industrial society, 1870–1945. In: Myrdal, J. and Morell, M. (eds.). *The agrarian history of Sweden: From 4000 BC to AD 2000*. Lund: Nordic Academic Press: 165–213.

Munro, L.J.A., Penning-Rowsell, E.C., Barnes, H.R., Fordham, M.H., and Jarrett, D. (1997). Infant mortality and soil type: A case study in south-central England. *European Journal of Soil Science* 48(1): 1–11. doi:10.1111/j.1365-2389.1997.tb00179.x.

Oliver, M.A. and Gregory, P.J. (2015). Soil, food security and human health: A review. *European Journal of Soil Science* 66(2): 257–276. doi:10.1111/ejss.12216.

Oris, M., Derosas, R., and Breschi, M. (2004). Infant and child mortality. In: Bengtsson, T., Campbell, C., and Lee, J.Z. (eds.). *Life under pressure: Mortality and living standards in Europe and Asia, 1700–1900*. London: MIT Press: 359–398.

Patz, J.A., Strzepek, K., Lele, S., Hedden, M., Greene, S., Noden, B., Hay, S., Kalkstein, L., and Beier, J.C. (1998). Predicting key malaria transmission factors, biting and entomological inoculation rates, using modelled soil moisture in Kenya. *Tropical Medicine and International Health* 3(10): 818–827. doi:10.1046/j.1365-3156.1998.00309.x.

Pettersson, L. (1989). Riksgäldskontoret, penningpolitiken och statsstödssystemet under tidigt 1800-tal. In: Dahmén, E. (ed.). *Upplåning och utveckling-Riksgäldskontoret 1789–1989*: Stockholm: Allmänna förlaget: 135–172.

Puleston, C.O. and Tuljapurkar, S. (2008). Population and prehistory II: Space-limited human populations in constant environments. *Theoretical Population Biology* 74(2): 147–160. doi:10.1016/j.tpb.2008.05.007.

Quaranta, L. (2013). Scarred for life. How conditions in early life affect socioeconomic status, reproduction and mortality in southern Sweden, 1813–1968. [PhD thesis]. Lund: Lund University, Department of Economic History.

Quaranta, L. (2015). Using the Intermediate Data Structure (IDS) to construct files for statistical analysis. *Historical Life Course Studies* 2: 86–107.

Quaranta, L. (2016). STATA Programs for using the Intermediate Data Structure (IDS) to construct files for statistical analysis. *Historical Life Course Studies* 3: 1–19.

Rocklov, J., Edvinsson, S., Arnqvist, P., de Luna, S.S., and Schumann, B. (2014). Association of seasonal climate variability and age-specific mortality in northern Sweden before the onset of industrialization. *International Journal of Environmental Research and Public Health* 11(7): 6940–6954. doi:10.3390/ijerph110706940.

Rodríguez, L., Cervantes, E., and Ortiz, R. (2011). Malnutrition and gastrointestinal and respiratory infections in children: A public health problem. *International Journal of Environmental Research and Public Health* 8(12): 1174–1205. doi:10.3390/ijerph8041174.

Rotberg, R.I. and Rabb, T.K. (1983). *Hunger and history*. Cambridge: Cambridge University Press.

Schaible, U.E. and Kaufmann, S.H. (2007). Malnutrition and infection: Complex mechanisms and global impacts. *PLoS Medicine* 4(5): 806–812. doi:10.1371/journal.pmed.0040115.

Schröder, W. and Schmidt, G. (2008). Mapping the potential temperature-dependent tertian malaria transmission within the ecoregions of lower Saxony, Germany. *International Journal of Medical Microbiology* 298(1): 38–49. doi:10.1016/j.ijmm.2008.05.003.

Schumann, B., Edvinsson, S., Evengard, B., and Rocklov, J. (2013). The influence of seasonal climate variability on mortality in pre-industrial Sweden. *Glob Health Action* 6: 20153. doi:10.3402/gha.v6i0.20153.

Swedish Geological Survey (SGU) (2014). Produkt: Jordarter 1:25.000–1:100.000 [electronic resource]. Uppsala: Sveriges geologiska undersökning. http://resource.sgu.se/dokument/produkter/jordarter-25-100000-beskrivning.pdf

Swedish Geological Survey (SGU) (2016). Jord [electronic resource]. Uppsala: Sveriges geologiska undersökning. http://www.sgu.se/om-geologi/jord/

Steduto, P., Hsiao, T.C., Raes, D., and Fereres, E. (2009). AquaCrop—The FAO crop model to simulate yield response to water: I concepts and underlying principles. *Agronomy Journal* 101(3): 426–437. doi:10.2134/agronj2008.0139s.

Svensson, P. (2001). Agrara entreprenörer. Böndernas roll i omvandlingen av jordbruket i Skåne ca 1800–1870. [PhD thesis]. Lund: Lund University, Department of Economic History.

Therneau, T.M. and Grambsch, P.M. (2000). *Modeling survival data: Extending the Cox model*. New York: Springer. doi:10.1007/978-1-4757-3294-8.

Van Poppel, F., Jonker, M., and Mandemakers, K. (2005). Differential infant and child mortality in three Dutch regions, 1812–1909. *Economic History Review* 58(2): 272–309. doi:10.1111/j.1468-0289.2005.00305.x.

Wolleswinkel-van den Bosch, J.H., van Poppel, F., Looman, C.W.N., and Mackenbach, J.P. (2000). Determinants of infant and early childhood mortality levels and their decline in the Netherlands in the late nineteenth century. *International Journal of Epidemiology* 29(6): 1031–1040. doi:10.1093/ije/29.6.1031.

Woods, R.I., Watterson, P.A., and Woodward, J.H. (1988). The causes of rapid infant mortality decline in England and Wales, 1861–1921 Part I. *Population Studies* 42(3): 343–366. doi:10.1080/0032472031000143516.

Zandbergen, P.A. (2007). Influence of geocoding quality on environmental exposure assessment of children living near high traffic roads. *BMC Public Health* 7(1): 37. doi:10.1186/1471-2458-7-37.

Appendix 1: Categorization of the SES v2 variable groups

The SES v2 variable groups are based on the following categorization.

- Large-scale farmers

    § Families having lands with a taxation value higher than 2/5 *mantal*.
    § Families with lands larger than 100 hectares and with a taxation value of at least 1/32 *mantal* (the threshold of 1/32 is set to exclude possible landless and semilandless families working on large farms).

- Farmers

    § Families with lands of 2–100 hectares and which have a taxation value of at least 1/64 *mantal* and at most 2/5 *mantal*.
    § Families with lands larger than 100 hectares and with a taxation value between 1/64 and 1/32 *mantal*.[7]
    § Families with lands smaller than 2 hectares and with a taxation value between 1/64 and 2/5 *mantal*.[7]

- Labourers

    § Landless families (e.g., soldiers, workers, and servants).
    § Families with lands smaller than 2 hectares and with a taxation value below 1/32 *mantal*.
    § Families having lands with a taxation value below 1/64 *mantal*.

When defining the SES variable, we considered lands with a taxation value of 1/32 or higher as a threshold for families being able to support themselves with that land (Svensson 2001). Therefore, a taxation value of half the size of this threshold; i.e., 1/64, is used as a lower limit for defining the farmers group. The upper limit for the farmers is set to 2/5 *mantal* because when using thresholds larger than 2/5, the models violated the proportional hazard assumption of Cox models for the continuous taxation value variable. Furthermore, lands with 2 hectares are considered as the lower limit for small-scale farms, whereas 100 hectares is considered as the lower limit for large-scale farms

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[7] These two groups are somewhat problematic. They may represent individuals with large and unproductive, or small and productive, lands, but also individuals with incorrect taxation information, or individuals working on large farms. However, the groups are small and constitute in total only 0.46% of the children's total time at risk.

(cf. Morell 2011). We employ this new categorization to enable the explicit study of those children; i.e., farmers' children, whose wealth, and hence mortality, should be most affected by the underlying soil type of the property unit.

Note that some of the selected limits of the area and taxation values that define the groups are arbitrary, as these limits are both time and context dependent; for example, the threshold of 2/5 *mantal* used as an upper limit for the farmers group. Therefore, as a sensitivity test, we also estimated models with other limits of taxation value and area. These results show that the effect of soil type on child mortality increases slightly when lowering the upper limits of the taxation value and area (not reported here) for the farmers' group, which indicates that the smaller the farm, the more sensitive its family may be to the underlying soil type.

Appendix 2: Explanatory variables used for sensitivity tests

This Appendix describes the explanatory variables used for various sensitivity tests, but which were not included in the results tables.

Land type – A categorical variable indicating whether the family lived on freehold/crown or manorial land. This variable can be used together with the taxation value as an alternative SES.

Property unit area – A continuous variable in hectare, which can be used as an alternative measure of wealth. We expect that property units with large areas are beneficial in general; on the other hand, large areas with poor soil could require harder work and more energy than smaller farms with fertile soil. Hence, hard work combined with malnutrition may increase mortality (Floud et al. 2011). Note that several property units in Kågeröd included forests, but we lack information on those areas.

Satellite units/demesnes. One problem with the property unit area is the presence of large commercial farms, called satellite units (Swedish: *Plattgård*) (cf., Lundh and Olsson 2011), and large demesnes. On such lands, mostly landless individuals such as crofters and other agricultural workers lived and worked. Thus, the area variable may be misrepresentative because the largest property units in the study area were all satellite units or demesnes. Therefore, we create a variable indicating whether individuals worked on such land or not.

Population density. Considered as an indicator of exposure to diseases. We define a categorical variable indicating whether the individuals were living in a property unit with a population density above or below the median value (73.45 individuals/km^2). We create the variable based on a simple measure of population density in which the annual number of individuals within each property unit is divided by the property unit area.