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Demographic Impacts of Climatic Fluctuations in Northeast China, 1749-1909*

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Abstract

We examine the demographic impacts of climatic fluctuations in northeast China in the late eighteenth century and the nineteenth century. Specifically, we focus on the consequences of extended periods of unusually cool summers, which in northeast China tended to be associated with poor grain harvests. During the period covered by the northeast Chinese population register data that we analyze, 1749-1909, there are three periods during which there were cool summers of unusual frequency or intensity: 1782-1789, 1813-1815, and 1831-1841. These periods coincided with major disruptions elsewhere in Asia that were climate-related. In Japan, the Tenmei famine took place in 1783-1786, and the Tenpo famine took place in 1833-1838. The Indonesian volcano Tambora erupted in April of 1815, and had adverse effects on climate around the world. We show that the period that coincided with the Tenmei famine in Japan was characterized by a massive mortality crisis, another that took place between 1810 and 1817 was characterized by a substantial reduction in fertility, and another that coincided roughly but not exactly with the Tenpo famine in the 1830s did not exhibit a pronounced mortality or fertility response. Patterns of responses revealed by our disaggregation by gender, age, socioeconomic status and other characteristics are a mixture of the expected and unexpected. Low-status individuals generally fared especially poorly, but there were cases where nominally high-status individuals also fared especially poorly.

Introduction

We examine the demographic impact of climatic fluctuations in northeast China in the late eighteenth century and the nineteenth century. Specifically, we focus on the consequences for mortality and fertility of three prolonged periods of unusually cool summers. During the period covered by the northeast Chinese population register data that we analyze, 1749-1909, there are three periods during which there were cool summers of unusual frequency or intensity: 1782-1789, 1813-1815, and 1831-1841 (Lee and Campbell 1997, 33-34; Wang 1988). At least in the region we study, fragmentary evidence suggests that the period around 1813-1815 was also characterized by heavy rains and flooding. In northeast China, cool summers tended to be associated with poor harvests because of a shortened growing season and the possibility of adverse conditions even during the summer (Feng, Li, and Li 1985). In Liaoning, all three of these periods were characterized by grain price increases of an intensity and duration suggestive of poor harvests (Lee and Campbell 1997, 33-34).

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The aim of this paper is to show that in historical China, the demographic response to major and sustained exogenous shocks was not restricted to increased mortality, but could also include reduced fertility. As discussed below, previous examinations of the role of demographic crises in historical Chinese population dynamics have mostly assumed that dramatic reductions in population size associated with major exogenous shocks such as prolonged wars and repeated poor harvests resulting from climatic shocks were attributable to increases in mortality (Chu and Lee 1994; Ho 1959; Zhang et al. 2006). This assumption has usually been implicit rather than explicit, and reflects the reliance of such studies on changes in population size for evidence of demographic crises. In these and other studies, little consideration has been given to the mechanisms underlying sudden or secular reductions in population size, in particular, the possibility that they were also the result of substantial reductions in fertility and increases in early infant and early child mortality, not solely the result of massive increases in mortality at later ages attributable to starvation or epidemics. We are agnostic as to whether reductions in fertility or increases in infant and early child mortality reflected deliberate behavior on the part of couples, or was the byproduct of other behaviors taken in response to adverse conditions.

To demonstrate that the demographic response to major and sustained exogenous shocks could include reductions in fertility as well as increases in mortality, we examine the mortality and fertility impacts of these three periods of cool summers. We begin with background. We introduce the region in northeast China that we study, focusing on its climate and the three periods of cool summers, and then contextualize this study by clarifying its relationship to previous studies of mortality and fertility fluctuations in Liaoning and their relationship to economic conditions, and previous studies of the influence of climate on demographic outcomes. In the second part of the paper, we introduce the data and methods used in the analysis. Finally, in the third part of the paper, we present results. We review trends and fluctuations in mortality and fertility to show that the first of the three periods of cool summers, 1782-9, was characterized by elevated mortality, and that the second and third periods were characterized by substantially reduced fertility. We then compare patterns of mortality by age and sex for 1780-3, 1783-6, and 1786-9 to identify the specific years in which the mortality response to climatic fluctuation was most severe, and which age and sex groups were most affected. Finally, we present results from discrete-time event-history analysis that differentiate fertility and mortality responses in the three periods by age, sex, and socioeconomic status.

Background

Our data cover a region in Liaoning province in northeast China, in the region sometimes referred to as Manchuria. Liaoning has a temperate, continental monsoon climate. Rain falls primarily in the summer. There is relatively little precipitation during the rest of the year. Winters are cold, with temperatures well below freezing, and the summers are hot. The area of Liaoning covered by our data has a short growing season, with about 180 frost-free days per year. The association of cool summers with

poor harvests Liaoning suggested in Feng, Li, and Li (1985) does appear to differ from the association between low winter temperatures and poor harvests typically observed in historical northern Europe (Galloway 1986, 8-9). We speculate that the association between cool summers and poor harvests reflects especially late spring frosts or early autumn frosts that damaged crops, or unusually heavy precipitation, not direct effects of a slightly lower average daily temperature.

Two of the periods of cold summers coincided with major economic and demographic disruptions elsewhere in East Asia that appear to have been climate-related. In Japan, the Tenmei famine took place in 1783-1786, and the Tenpo famine took place in 1833-1838. These were among the most serious famines of the Tokugawa era. In both cases, the effects were most severe in northern Japan. Both famines appear to have been associated with cool weather and excessive rain that led to especially poor rice harvests. Eventually, comparison of results between Liaoning and Japan on mortality and fertility differentials in responses to these events will illuminate how social and family organization mediated their impact on individuals, just as comparisons of patterns of responses to grain price fluctuations have illuminated how households and communities managed milder forms of economic stress (Bengtsson, Campbell, Lee et al. 2004; Tsuya et al. 2010).

The first two periods also coincided with major events much further afield that had powerful effects on climate and by extension demographic behavior and the economy. In 1783, the Laki volcano erupted in Iceland, disrupting weather in the northern hemisphere for several years. England experienced substantially elevated mortality in 1783 and 1784 that has been linked to the Laki eruption (Witham and Oppenheimer 2005). In 1784, the winter in North America was the longest and coldest on record. In Japan, Asama also erupted in 1783, but its effects are likely to have been more local, and less likely to have affected climate in northeast China. In 1815, the Tambora volcano erupted in Indonesia, disrupting weather worldwide (Oppenheimer 2003). For example, in 1816, the northeast United States, maritime Canada, and Europe experienced unusually cold weather, and the year became known as the "Year Without A Summer." In Europe and North America, crops failed and livestock died, leading to what Post (1977) referred to as "the last great subsistence crisis in the western World."

This study extends upon earlier examinations of the demographic impact of periods of cold summers in Liaoning that found that the second and third were associated with elevated mortality and/or depressed fertility (Lee and Campbell 1997). This study makes use of a much expanded dataset that covers a much larger swath of the province, representing a much wider variety of ecological and economic contexts. The dataset in the original study only covered a small collection of communities just to the north of what is now Shenyang. The larger dataset in this study increases confidence that observed phenomena are regional, not idiosyncratic local variations peculiar to a small cluster of communities. The dataset used in this study is also large enough to follow Bengtsson, Campbell, Lee et al. (2004) and Tsuya et al. (2010) and differentiate mortality and fertility responses to periods of cold summers by socioeconomic status, household context and other individual characteristics. Finally, the larger dataset allows

for a detailed examination of the period 1782-1789. In the earlier study, there was too little data from that period to compare its mortality and fertility patterns to early or later periods.

Previous studies of demographic responses to variations in economic conditions mostly used grain price series as indices of harvests and by extension weather conditions. Early studies examined the influence of grain price variations on crude rates of birth, death, and marriage (Galloway 1988; Wrigley and Schofield 1981). More recent studies examine patterns of variations by age, sex, socioeconomic status and family context in the demographic responses to variations in grain prices (Bengtsson, Campbell, Lee et al. 2004; Campbell and Lee 1996, 2000, 2004; Tsuya et al. 2010). Grain prices reflected local harvests and in these studies were intended as an index of food consumption. Higher prices tended to reflect poorer harvests. Subsistence farmers had less to eat, and families with non-agricultural incomes who bought their food faced higher prices in the market. The implicit assumption in such studies was that the response of demographic rates to changes in grain prices was linear, so that for example, a ten increase in prices had twice the effect of a five increase in prices.

By focusing on the demographic impact of extended periods of extreme weather, this study complements others that examine the impact of price fluctuations. Grain prices may not have been a perfect indicator of harvest outcomes or the weather conditions that helped determine them. In Liaoning and elsewhere, grain prices may also have reflected economic conditions unrelated to local harvests, for example, changes in the supply or demand of grain elsewhere, state intervention in markets, or fiscal phenomena such as inflation or deflation. According to Figure 1, which presents annual sorghum prices in Liaoning, the three periods of cold summers that are the focus of this study were indeed characterized by grain prices increases large enough to be suggestive of extremely poor harvests. However, price increases are also apparent in years that were not identified as period of cold summers, especially later in the nineteenth century. If elevated prices in these other periods reflected factors other than harvest outcomes, periods of cold summers may have been more likely to be periods of hardship than periods of high grain prices.

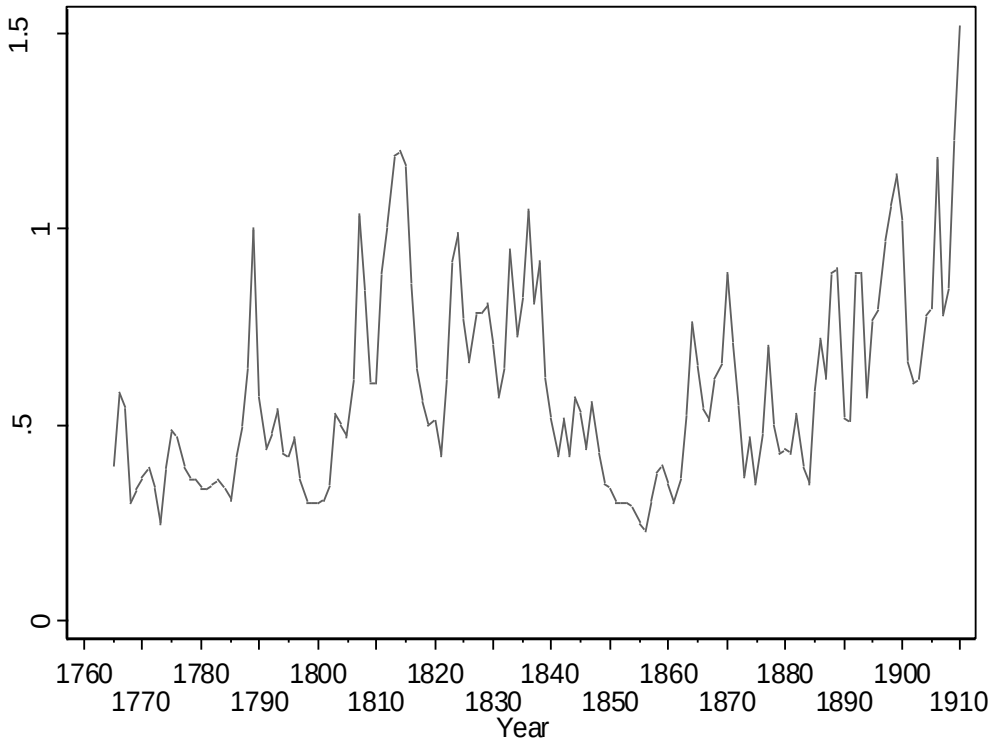


Figure 1. Annual low sorghum prices, Liaoning, 1765-1912.

This study advances upon earlier studies that examine the effects of climate on population because of its focus on the effects of multiple years of bad weather. Previous studies have tended to focus on the very long term or the very short term by looking at relationships over centuries or single years. An early study that directly addressed the role of climate in population dynamics, Galloway (1986), focused on the implications of secular changes in climate for trends in population size. He was interested primarily in the influence of centuries-long periods of warming or cooling on total population size. A similar study focused specifically on China over the last millennium argues that climatic variation was a more important determinant of population trends over the long term than dynastic cycles, Malthusian processes, and other mechanisms (Lee, Fok, and Zhang 2008). Another study, Galloway (1994), applies distributed-lag models time series to demographic rates, temperature, and grain prices in Europe. The focus in that study is whether unusually high or low temperatures in specific seasons are associated with elevated mortality in the same year. It did not allow for the possibility explicitly considered here that while a historical population might have been able to ride out a single bad harvest, a succession of bad harvests might have had catastrophic results.

This study contributes to the literature on demographic crises in past times by differentiating fertility and mortality responses to the periods of cold summers by family context and socioeconomic status. The large existing literature on demographic crises before the twentieth century, especially famines and epidemics, relies heavily on aggregated data on total numbers of births and deaths, and on written accounts by

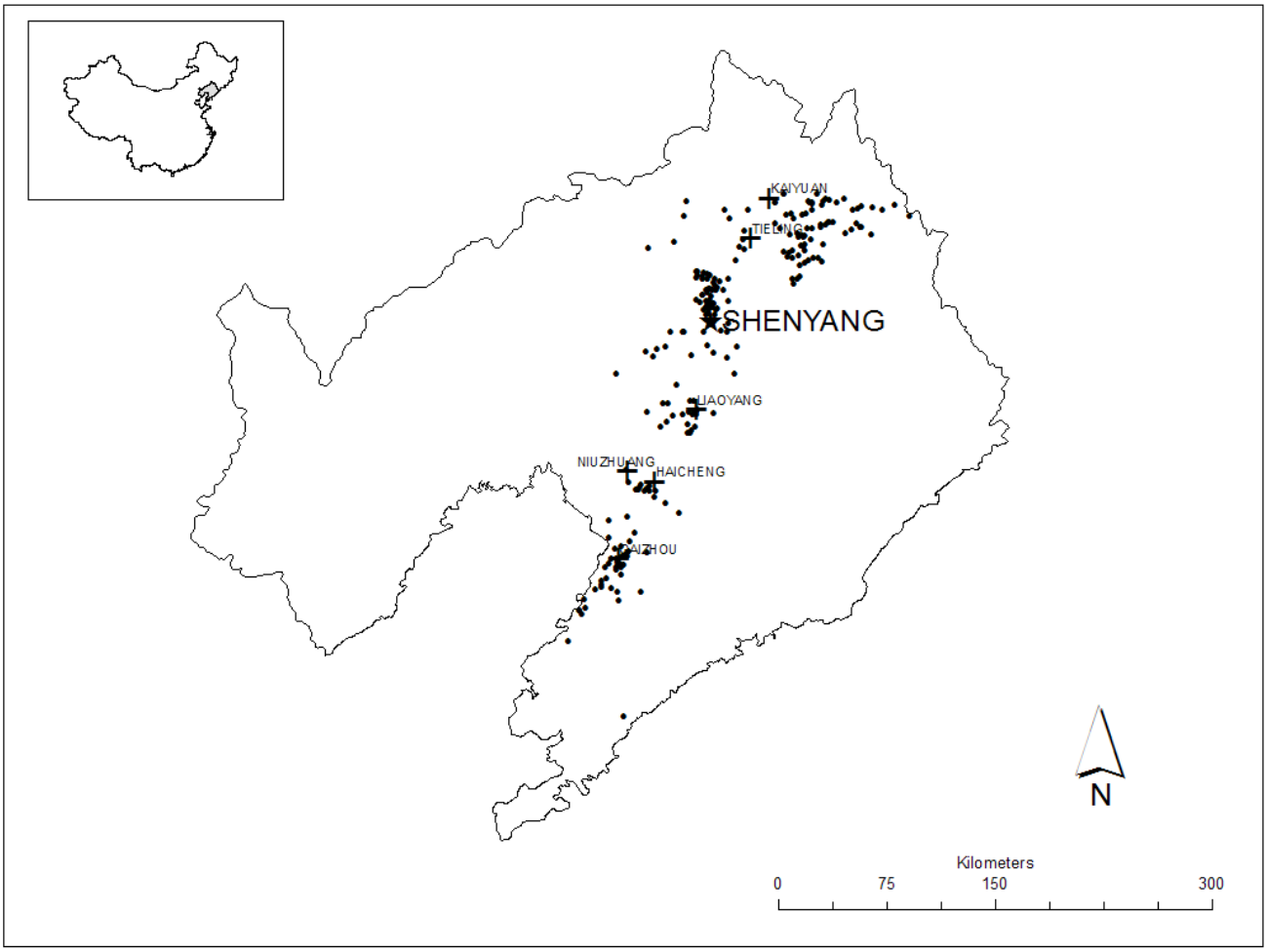
contemporaries about harvest failures, famines, and other disasters (Walter, Schofield, and Appleby 1991). Only a few studies of famines, epidemics, and other demographic crises have disaggregated mortality or fertility responses by age or sex (Dyson and Ó Gráda 2002). As a result, most assessments of the long-term consequences of demographic crises before the twentieth century assume patterns of effects by age and sex based on data from famines and other crises in developing countries during the twentieth century (Watkins and Menken 1985; Menken and Campbell 1992).

Data

The data we analyze consists of triennial household register data for 1749 to 1909 for more than 600 villages in Liaoning province in northeast China. The database comprises 1.4 million observations of one-quarter million people who lived in 28 administrative populations between 1749 and 1909. We have been able to produce such historical data because of the internal consistency of the core household register data, their availability through the Genealogical Society of Utah and the Liaoning Provincial Archives, and the sustained efforts of teams of colleagues and data entry personnel in the People's Republic of China. We have already described the origins of the registers as well as our procedures for data entry, cleaning and linkage in Lee and Campbell (1997, 223-237).

The features of the registers relevant for studying demographic and social outcomes have been described in published investigations of mortality differentials (Campbell and Lee 1996, 2000, 2002b, 2004), transmission of household headship (Lee and Campbell 1998), migration (Campbell and Lee 2001), ethnic identity (Campbell, Lee, and Elliott 2002), social mobility (Campbell and Lee 2003b), the influence of secular economic change on demographic behavior (Lee and Campbell 2005), and kinship organization (Campbell and Lee 2002a). The description of the data here is based in large part on the discussions of the data in these publications, Lee and Campbell (1997), and Campbell and Lee (2002a).

The geographic and economic contexts of these populations varied. As Map 1 shows, more than 600 Liaoning villages are arranged in four distinct regions spread over an area of 40,000 square kilometers, larger than the province of Taiwan. These regions include a commercialized coastal area around Gaizhou, a farming region around Haizhou and Liaoyang that we identify as Liaoning South Central, an administrative center on the Liaodong Plain around the city of Shenyang that we refer to as Liaoning Central, and a remote agricultural area in the hills and mountain ranges in the northeast that we refer to as Liaoning Northeast. The institutions, regions and communities covered in the data are diverse enough that even if the population is not representative of China or even Liaoning in a formal statistical sense, results are likely to be relevant for understanding family and social organization in other parts of China.



Map 1. Liaoning communities covered by the household register data, 1749-1909.

The Liaoning household registers provide far more comprehensive and accurate demographic and sociological data than other household registers and lineage genealogies available for China before the twentieth century (Harrell 1987, Jiang 1993, Skinner 1986, Telford 1990). This is because the Northeast, which was the Qing homeland, was under special state jurisdiction, distinct from the provincial administration elsewhere. Regimentation of the population actually began as early as 1625, when the Manchus made Shenyang their capital and incorporated the surrounding communities into the Eight Banners (Ding 1992; Ding et al. 2004; Elliott 2001). By 1752, with the establishment of the General Office of the Three Banner Commandry, the population was also registered in remarkable precision and detail, and migration was strictly controlled, not just between Northeast China and China Proper, but between communities within Northeast China as well. Government control over the population was tighter than in almost any other part of China (Tong and Guan 1994, 1999). Movement within the region was annotated in the registers, and individuals who departed the area without permission were actually identified in the registers as 'escapees' (taoding).

The Qing state implemented a system of internal cross-checks to ensure the consistency and accuracy of the registers. First, they assigned every person in the banner population to a residential household (*linghu*) and registered him or her on a household certificate (*menpai*). Then they organized households into groups (*zu*), and compiled annually updated genealogies (*zupu*). Finally, every three years they compared these genealogies and household certificates with the previous household register to compile a new register. They deleted and added people who had exited or entered in the previous three years and updated the ages, relationships, and official positions of those people who remained as well as any changes in their given names. Each register, in other words, completely superseded its predecessor.

The result was a source that closely resembled a triennial census in terms of format and organization. Entries in each register were grouped first by village, then by household group (*zu*) and then by household. Individuals in a household were listed one to a column in order of their relationship to the head, with his children and grandchildren listed first, followed by siblings and their descendants, and uncles, aunts, and cousins. Wives are always listed immediately after their husbands, unless a widowed mother-in-law supersedes them. For each person in a household, the registers recorded relationship to household head; name(s) and name changes; adult occupation, if any; age; animal birth year; lunar birth month, birth day, and birth hour; marriage, death, or emigration, if any during the intercensal period; physical disabilities, if any and if the person is an adult male; name of their household group head; banner affiliation; and village of residence.

The registers also record official positions held by adult males. We have identified four broad categories of official position: banner, civil service, examination, and honorary. These constituted the local elite. The first three categories were formal governmental offices and included a salary and other perquisites. They predominantly comprise lower-level occupations such as soldier, scribe, or artisan. Positions also included some high administrative offices that entailed not only a salary, but substantial power as well. Positions and titles in the fourth category, honorary, were typically purchased, and indicate substantial personal resources or access to such resources through the family. For the purposes of this analysis, we do not distinguish among the various categories of position. While the positions varied in terms of the incomes they implied, the incomes associated with even the most humble of positions were substantial by the standards of the area.

The registers distinguish disabled adult males, classified as *feiding* or *chenfei*, from other adult males (Lee and Campbell 1997). Campbell and Lee (2003a) assess the quality of the disability data and examine causes and consequences of being recorded as detailed in detail. Classification as disabled could occur for any one of a number of reasons and until 1786, the registers generally specified a specific disease or condition for each disabled male. Reflecting the prevalence of tuberculosis in the eighteenth and nineteenth centuries, respiratory diseases, especially consumption (*laozheng*), were by far the most common, affecting more than 5 percent of adult males and 25 percent of all the disabled. Eye diseases were second most common, affecting more than 3 percent of

adult males and 15 percent of the disabled, followed by such neurological disorders as retardation, insanity, dementia, and epilepsy which affected and afflicted 2 percent of adult males and 10 percent of the disabled.

In contrast with most historical censuses, the triennial registers allow for linkage of the records of an individual across time. Households and their members appeared in almost the same order in each register, even if they moved to another village. Linkage from one register to the next is straightforward: as our coders transcribe each new register, for each individual they list the record number of his or her entry in the previous register. Since the coders transcribe each new register by copying over the file for the preceding register and then editing it, this is straightforward. From the linked records for each individual, we reconstruct life histories. By comparing observations for the same individual in successive registers, we can construct outcome measures indicating whether particular events or transitions took place in the time between two successive registers.

These registers have a number of features that distinguish them as a source for historical demography. The population is closed, in the sense that the registers followed families that moved from one village to another within the region. Entries into and exits from the region were rare, and when they did occur, their timing was recorded or can be inferred (Lee and Campbell 1997, 223-237; Lee and Wang 1999, 149-153). In contrast with historical Chinese demographic sources such as genealogies that only record adult males, the Liaoning registers record most boys and some girls from childhood, as well as all women from the time of their marriage. Unlike genealogies, they also provide detail on village and household residence. In contrast with parish registers, an important source for European historical demography, they allow for precise measurement of the population at risk of experiencing most demographic events and social outcomes.

The most serious limitations of the registers relevant to this analysis are the frequent omission of boys who died in infancy or early childhood, and the omission of most daughters. As a result, we cannot reliably estimate infant or early childhood mortality for boys or girls. While we can produce reliable estimates of mortality in later childhood and early adolescence for boys, we cannot do so for girls. Our analysis of fertility, meanwhile, is based on boys who survived long enough to be included in the registers. Apparent fertility differentials may also reflect differentials in infant and child survival. When we produce estimates of the Total Fertility Rate, we first calculate a TFR based on the recorded boys, multiply by 1.5 on the assumption that one-third of boys died without ever being recorded, and then multiply by (100+105)/105 to include an estimate of the number of girls who were born.

Methods

To examine differences in the mortality impact of the periods of cold summers, we estimate discrete-time event-history models. Following the approach in previous studies of mortality with these data, we estimate logistic regressions in which the

dependent variable is an indicator of whether an individual died in the next three years or not (Campbell and Lee 1996, 2000, 2002b, 2004, 2009). Models include controls for age and year, in the form of a fourth-order polynomial for age and a third-order polynomial for year. Models also included variables of substantive interest described below, and interactions between these variables and whether the record is for 1783-1786. We focus on the differential mortality impacts of the period 1783-1786 because our descriptive results demonstrate unambiguously that this was a period of extraordinarily high mortality. Differentiating mortality patterns for this period identifies the population subgroups that were most adversely affected by this catastrophe. Descriptive results indicate that mortality effects of the other two periods of cold summers were limited.

The analysis of male mortality used all the observations for which the immediately succeeding register or the one after that was also available. In the situations where the immediately succeeding register was not available but the one that followed was available and the male was recorded there, either as still alive or as having died in the time since the missing register, an observation was created to serve as a filler record to indicate whether the male died in the period between the missing register and the one following. If the male was not present in the later register, they were assumed to have died in the time between the first register and the missing register, and the outcome variable in the first register set accordingly. For female mortality, analysis was based on records of live married and widowed women for whom the immediately succeeding register was available. In cases where an intervening register was missing, it was not possible to create and insert a record because women who disappeared between the first register and the missing register might have remarried and left the household, not died.

For fertility, we estimate a Poisson regression on annualized data in which the outcome is a count of the number of births attributed to a married woman in a year. We focus on the periods 1782-1789, 1810-1817, and 1837-1841. In each of these three cases, we estimate a model that includes controls for age and year, right-hand side variables of substantive interest, and interactions between these variables and an indicator of whether the observation falls into one of these periods. The annualized data for the fertility analysis were created from the original triennial register data by creating additional records in the registers for the years between registers. In these records, women were aged forward, and other information copied forward from their most recent register entry. Through record linkage of children to their parents, counts of the numbers of births attributed to them in each year were constructed. We restrict analysis to the annualized records of women in the years where there was at least one observation of the woman in the original registers 5 to 9 years later, by which time any child they bore would have had a chance to be registered.

In differentiating the demographic impact of climatic fluctuations, we focus on the role of socioeconomic characteristics. Specifically, we measure socioeconomic status with three dichotomous indicator variables: official position, disability, and diminutive name. For adult males, the variables reflect their own status. For women,

they reflect husband's status. For boys, the variables reflect father's status. For boys, we also include an indicator of whether or not they were recorded with a diminutive name. Disability status was a measure of socioeconomic status in the sense that in a preindustrial society like the one studied, most of the conditions associated with being listed as disabled implied impaired capacity for contributing agricultural labor to the household. We use diminutive names as an indicator of status because prior exploratory analysis has revealed that boys and adult males recorded with such names appeared to have less favorable socioeconomic outcomes. While diminutive names may not have been as precise a marker for socioeconomic status as official position, many more men were recorded with such names than were listed as having an official position.

For boys, we also examine how the presence or absence of parents conditioned the mortality impact of the cold summers between 1783 and 1786. We include dummies for whether or not their father and mother were alive, along with interactions with the indicator for 1783-1786. Based on previous findings that the absence of a parent, especially a mother, increases child mortality in the short-term and even the long term (Campbell and Lee 2002b, 2009), we expect boys who lost a parent to have suffered disproportionately when times were bad.

For fertility, we also examine how a married woman's childbearing history conditioned the response during the periods of cold summers. Specifically, we contrast the changes in fertility during periods of cold summers according whether women had no registered male births, one, two, or three or more. This comparison will yield insight into whether fertility responses reflected deliberate behavior that was conditioned by the number of boys that had already been born. To the extent that fertility responses to periods of poor weather reflected deliberate postponement of births, we expect a stronger effect for later births than for earlier births, on the assumption that couples without any sons may have been less willing to postpone than couples with sons.

Results

Descriptive

According to Figure 2, period life expectancy at age 1 *sui* ranged between 30 and 40 years in the middle of the eighteenth century, plummeted to around 15 years for males and 20 years for females between 1783 and 1786, then exhibited a slow upward tendency through the nineteenth century into the beginning of the twentieth century. According to Figures 3 through 5, which summarize trends in the probability of surviving from age 1 *sui* to age 15 *sui*, the probability of surviving from age 16 *sui* to 55 *sui*, and life expectancy at age 56 *sui*, mortality rose at all ages in the years between 1783 and 1786. According to Figure 3, only one-quarter of males aged 1 *sui* would survive to age 15 *sui* if they experienced the mortality of the period 1783 to 1786 through childhood and early adolescence. In other time periods, anywhere between two-thirds and four-fifths of men would be expected to survive. According to Figure 4, only about one-tenth of males aged 16 *sui* would survive to age 55 *sui* if they experienced the mortality of the period 1783 to 1786 all the way through adulthood.

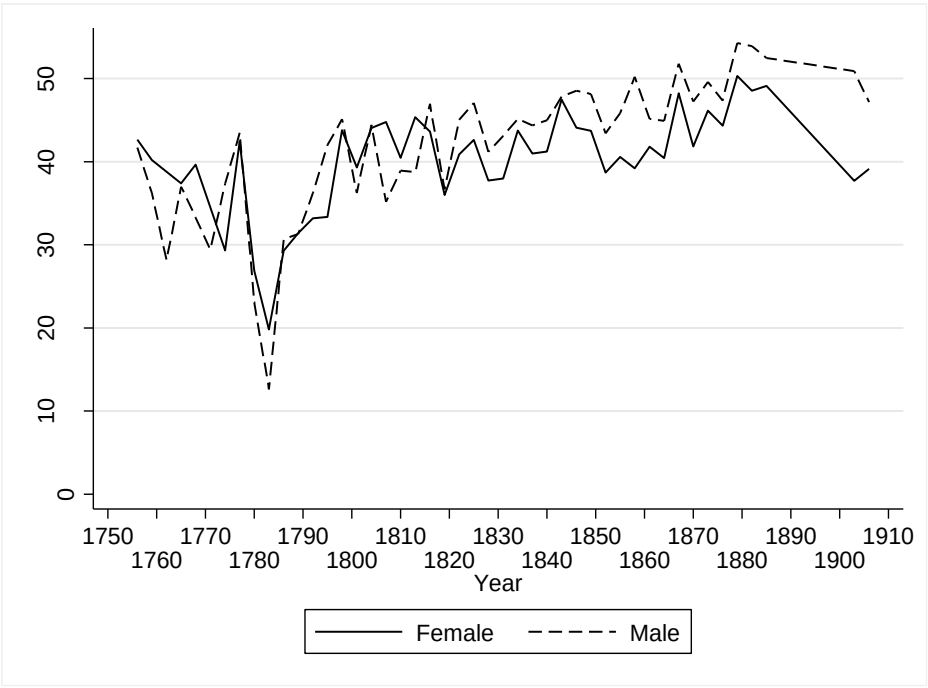


Figure 2. Life expectancy at age 1 *sui* by year, Liaoning, 1749-1909.

Figure 3. Probability of surviving from age 1 *sui* to age 16 *sui* by year, 1749-1909.

Figure 4. Probability of surviving from age 16 *sui* to 56 *sui* by year, 1749-1909.

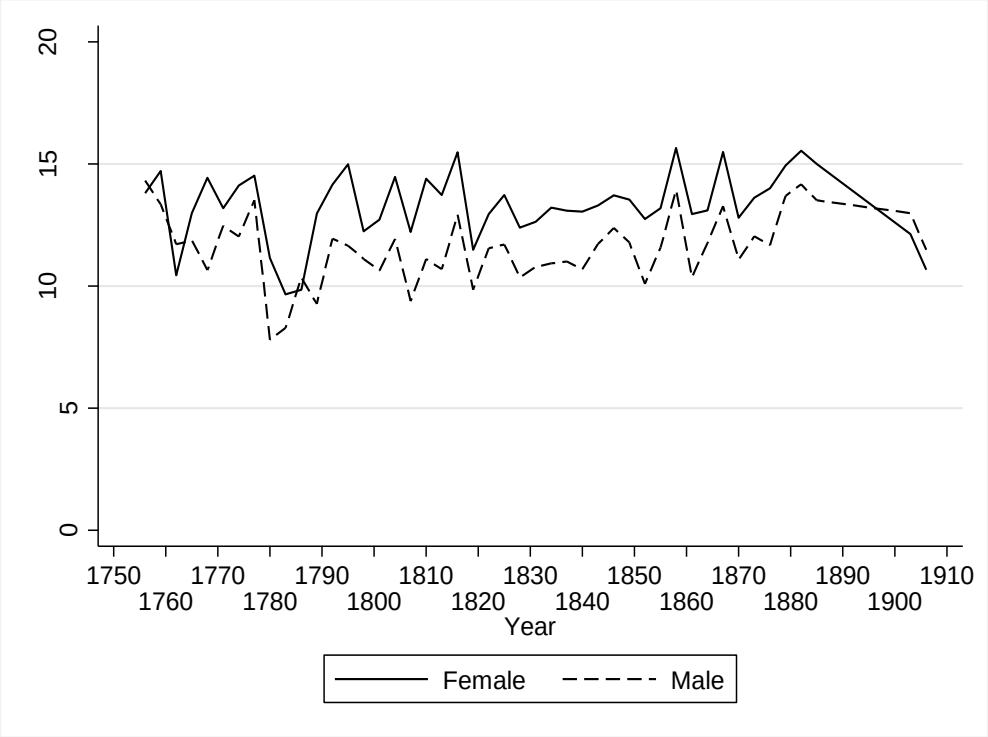


Figure 5. Life expectancy at 56 *sui* by year, 1749-1909.

Mortality crisis is apparent only in the first period of cold summers, 1782 to 1789. Table 1 confirms the impression from the reviews of Figures 2 through 5 that mortality change in the latter two periods was negligible. According to the odds ratios from a logistic regression that included polynomials to control for age and date and indicator variables for periods characterized by cold summers, mortality between 1810 and 1819 was slightly below trend. Mortality between 1837 and 1843 was only slightly above trend. Accordingly, subsequent examination of differentials in the mortality response to cold summers is focuses on the period from 1780 to 1789, especially between 1783 and 1786.

Table 1. Mortality variation in three periods of cold summers, Liaoning, 1749-1909.

Variable	Odds Ratio	p-value
Time Period (Ref: Remaining years 1749-1909)		
1783-1786	2.87	0.00
1810-1819	0.83	0.00
1837-1843	1.07	0.00
N	1162706	

Notes: Models also included a fourth-order polynomial to control for age and a third-order polynomial to control for year. Observations included males age 1-75 *sui* and ever-married females aged 16-75 *sui*.

Male child and early adolescent mortality and adult female mortality increased most dramatically in the period between 1783 and 1786. Figures 6 and 7 present the ratios of age-specific mortality rates for 1780 to 1783, 1783 to 1786, and 1786 to 1789 to rates in the baseline years 1749 to 1780 and 1789 to 1804. Table 2 details the age and sex pattern of mortality increase between 1783 and 1786 by presenting age- and sex-specific odds ratios for mortality in that period, relative to time trend as represented in a polynomial. According to these figures, male mortality in childhood and adolescence, and female mortality in early adulthood, increased fivefold or sixfold in 1783 to 1786 compared to the years earlier and later. Increases at other ages were substantial as well. Above age 55, mortality increases were limited, in keeping with the results on life expectancy at age 56 *sui* in Figure 5.

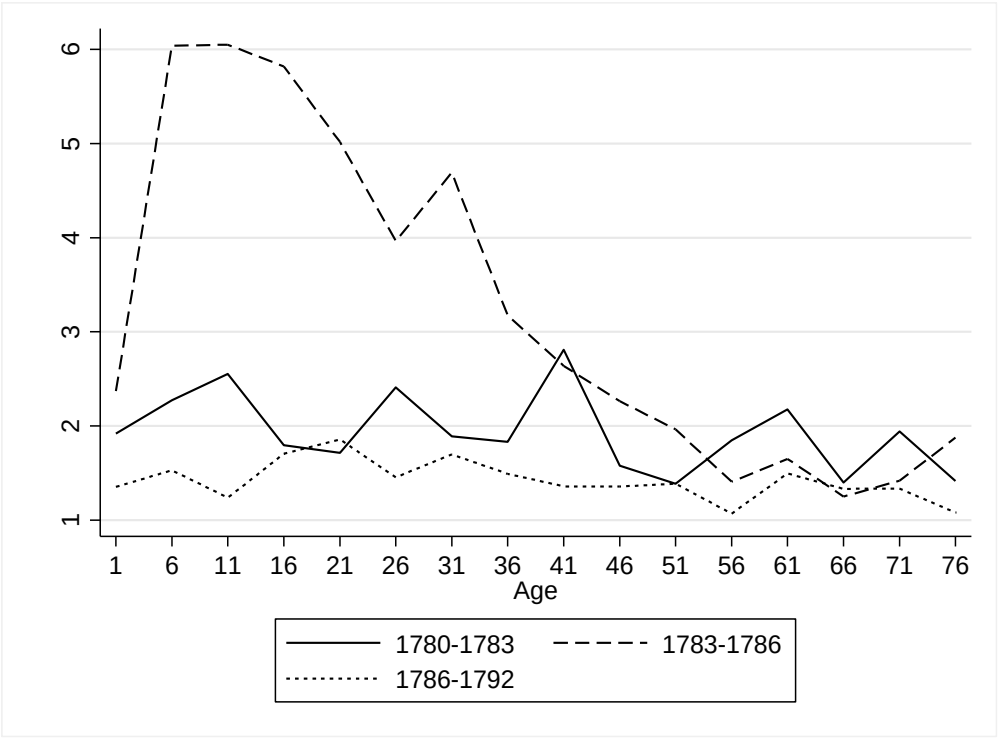


Figure 6. Male age-specific patterns of mortality increase, 1780-1792 compared to 1749-1780, 1792-1804.

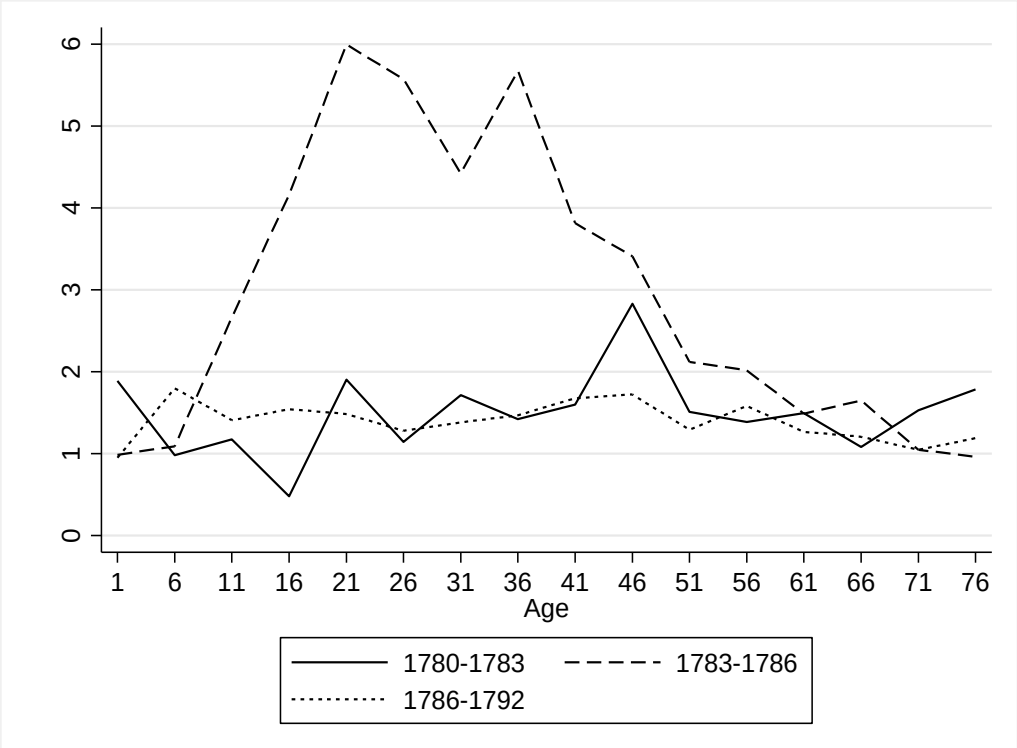


Figure 7. Female age-specific patterns of mortality increase, 1780-1792 compared to 1749-1780, 1792-1804.

Table 2. Age- and sex- specific mortality increases in the odds of dying, Liaoning, 1783-1786.

	Odds Ratio (Relative to same age/sex combination, 1749-1909)
Males	
1-5 *sui*	3.59
6-15 *sui*	8.78
16-35 *sui*	4.38
36-55 *sui*	2.00
56-75 *sui*	1.31
Married and Widowed Females	
16-35 *sui*	4.65
36-55 *sui*	2.78
56-75 *sui*	1.28
N	792460

Notes: Based on results from a logistic regression of the chances of dying for men ages 1-75 *sui* and married and widowed women ages 16-75 *sui* in north and central Liaoning, 1749-1909. Odds ratios presented in table were computed by multiplying the odds ratio for the specified age/sex group by the main effect of 1783-1786, which referred to males age 56-75 *sui*. Controls included a fourth-order polynomial for age and a third-order polynomial for year.

Fertility reductions were apparent around the time of the periods of cold summers, but they did not line up precisely. Figure 8 presents annual estimates of the Total Marital Fertility Rate, the number of births a women would have if she married at age 16 *sui* and remained married until she was age 50. Fertility was mildly depressed from 1786 to 1790, severely depressed for the seven years from 1810 to 1817, and mildly depressed again from 1837 to 1841. The tendency for fertility to be depressed around the time of recorded cold summers, but not exactly in those years, raise the possibility that cold summers were just one feature of the poor weather that affected demographic behavior, and that neighboring years in which the summers were not cold were nevertheless adverse for other reasons, and that in some years of cold summers were counterbalanced by other, more favorable features of the weather. On the assumption that the specific years of low fertility were the ones in which conditions for childbearing were most adverse, we focus on differential fertility changes in those years, even if they do not line up precisely with the years of cold summers.

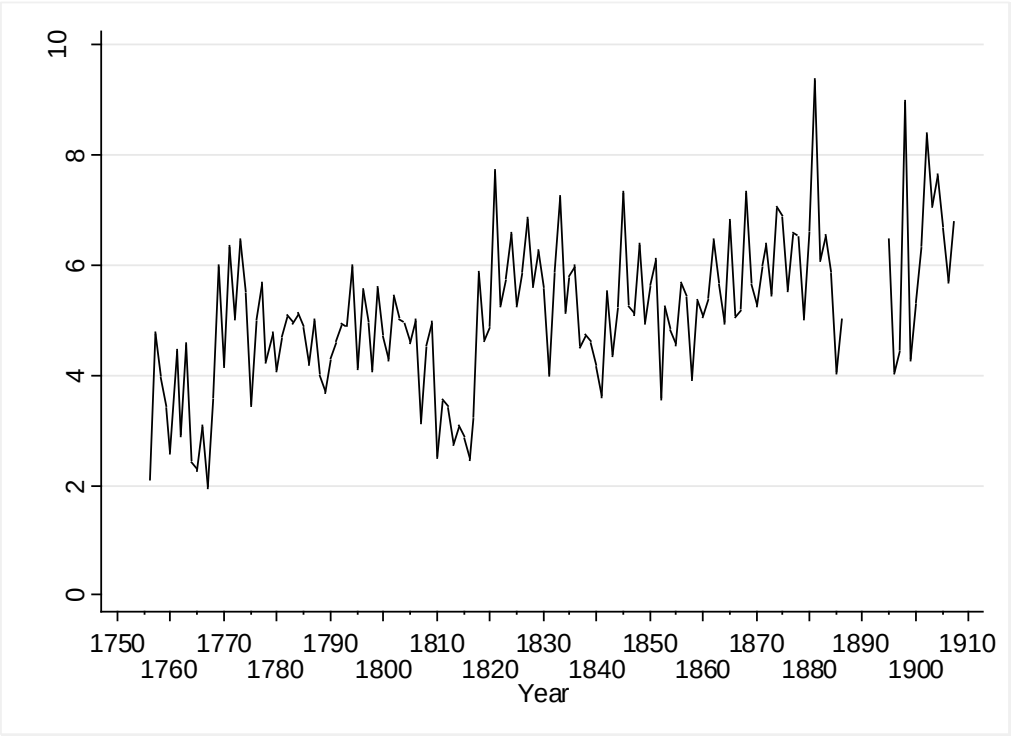


Figure 8. Estimated Total Marital Fertility Rate by year, 1749-1909.

Differential Responses

Patterns of change in child mortality in the period between 1783 and 1786 are mostly as would be expected if the mortality increases were most pronounced among the least advantaged, with the prominent exception of the mortality response of the sons of officials. Table 3 presents results from an analysis of child mortality in which an indicator for period 1783 to 1786 is interacted with indicators of social and family circumstances. Boys who had lost their mothers appear to have been especially vulnerable between 1783 and 1786, but the effect is not statistically significant. Child mortality rose much more in northern Liaoning, a hilly, forested and remote area, than in central Liaoning, the agricultural area around what is now Shenyang. Boys who had a diminutive name were affected much more than boys who did not have one. Unexpectedly, however, boys who were the sons of men who held official position experienced greater mortality increases during this period than boys whose fathers did not hold position.

Table 3. Differential mortality change in 1783-1786, children 1-15 *sui*, Liaoning 1749-1909.

	Odds Ratio	p-value
1783-1786	1.49	0.06
Age 1-5 *sui* (Ref: 6-15 *sui*)	1.02	0.75
Northern Liaoning (Ref: Central)	0.95	0.10
Father Alive	1.02	0.71
Mother Alive	0.91	0.05
Father Disabled	1.00	0.95
Father has Official Position	1.21	0.00
Father has Diminutive Name	1.01	0.91
Diminutive Name	0.96	0.18
1783-1786*		
Age 1-5 *sui* (Ref: 6-15 *sui*)	0.31	0.00
Northern Liaoning (Ref: Central)	1.88	0.00
Father Alive	1.20	0.47
Mother Alive	1.50	0.12
Father Disabled	12.54	0.00
Father has Official Position	2.23	0.02
Father has Diminutive Name	1.35	0.18
Diminutive Name	1.67	0.00
N	129456	

Notes: Based on data for north and central Liaoning. Controls included a fourth-order polynomial for age and a third-order polynomial for year. To save space, the results for these controls are not included here.

Among adults, the pattern is similar. Once again, increases in mortality are most pronounced for groups that would be expected to be the least advantaged, except that men who were officials experienced a more substantial increase than other men. Table 4 presents the results from logistic regressions of adult male and female mortality. Northern Liaoning, which because of its hilliness and relative inaccessibility is even now is the least well-off of the regions of Liaoning covered by the data, experienced the most substantial increase in mortality. Men who were disabled, and the women who were married to them, experienced a larger mortality increase than other men and women. Men and women who were childless experienced a much larger mortality increase than other men and women. However, once again, official position has an unexpected effect: men who held official position experienced a more substantial mortality increase than other men. Their wives, however, did not experience a disadvantage.

Table 4. Differential mortality change in 1783-1786, adults 16-55 *sui*, Liaoning 1749-1909.

	Males		Females	
	Odds Ratio	p-value	Odds Ratio	p-value
1783-1786	0.96	0.81	1.18	0.34
Age 36-55 (Ref: 16-35 *sui*)	1.06	0.30	1.10	0.06
Northern Liaoning (Ref: Central)	0.95	0.01	1.07	0.00
Disabled	1.07	0.02	1.01	0.75
Official Position	1.16	0.00	0.94	0.19
Diminutive Name	1.10	0.00	1.05	0.22
Widowed	1.23	0.00	1.34	0.00
Never-Married	1.18	0.00		
Childless	1.02	0.39	1.44	0.00
1783-1786*				
Age 36-55 (Ref: 16-35 *sui*)	0.48	0.00	0.78	0.05
Northern Liaoning (Ref: Central)	4.17	0.00	2.81	0.00
Disabled	2.56	0.00	5.57	0.00
Official Position	2.16	0.01	1.31	0.42
Diminutive Name	0.90	0.41	1.12	0.43
Widowed	1.00	0.99	0.30	0.05
Never-Married	0.94	0.68		
Childless	1.81	0.00	2.53	0.00
N	308028		227955	

Notes: Based on data for north and central Liaoning. Controls included a fourth-order polynomial for age and a third-order polynomial for year. For females, variables for disabled, position, etc. refer to husband's status. To save space, the results for these controls are not included here.

In old age, the same pattern was apparent. Table 5 presents results from logistic regressions of male and female mortality in old age. Interactions with the indicator for years between 1783 and 1786 reveal that childless men and women experienced much larger increases in mortality than other men and women. Results for adults and the elderly on the effects of the presence of children are consistent with previous findings that adults, especially women, had lower mortality overall if they had surviving children (Campbell and Lee 1996, 2002b, 2004.) The results here suggest that during an extraordinary crisis, adults with children were also better insulated than those without. The insulating effect of the presence of children is much clearer here than in the study of differences in mortality responses to grain prices in Campbell and Lee (2004). Women married to men who in old age still retained a diminutive name also experienced larger mortality increases than other women. Men who retained an undignified diminutive name in old age are likely to have been unusual, almost certainly of low socioeconomic status, thus this result is not unexpected. However, privilege in the form of an official position once again had an adverse effect: women married to officials experienced larger mortality increases than other women.

Table 5. Differential mortality change in 1783-1786, adults 56-75 *sui*, Liaoning 1749-1909.

	Males		Females	
Variable	Odds Ratio	p-value	Odds Ratio	p-value
1783-1786	0.89	0.56	0.98	0.95
Northern Liaoning (Ref: Central)	1.06	0.02	1.03	0.26
Disabled	0.98	0.34	1.04	0.17
Official Position	1.21	0.00	0.89	0.02
Diminutive Name	0.98	0.60	0.91	0.19
Widowed	1.19	0.00	1.18	0.00
Never-Married	0.92	0.08		
Childless	1.00	0.88	1.03	0.42
1783-1786*				
Northern Liaoning (Ref: Central)	0.86	0.61	0.91	0.82
Disabled	1.39	0.10	1.29	0.30
Official Position	1.26	0.56	3.14	0.01
Diminutive Name	1.03	0.91	1.86	0.08
Widowed	0.82	0.31	0.85	0.54
Never-Married	1.48	0.21		
Childless	1.74	0.01	3.02	0.00
N	61744		56304	

Notes: Based on data for north and central Liaoning. Controls included a fourth-order polynomial for age and a third-order polynomial for year. For females, variables for disabled, position, etc. refer to husband's status. To save space, the results for these controls are not included here.

Reductions in fertility were most pronounced in the second of the three periods, and differentials in response most apparent for that period as well. According to Table 6, which measures fertility reductions in the three periods in a model that includes polynomials to control for age and year as well as other control variables, fertility was only about 10 to 12 percent below trend in 1786 to 1790 and 1837 to 1841, but more than 40 percent below trend between 1810 and 1817. According to the logistic regression results in Table 7, reductions between 1810 and 1817 were most pronounced in north Liaoning and south Liaoning, and less pronounced in central and south central Liaoning. They were most pronounced for women married to men who held diminutive names, and least pronounced for women married to men who held official position. Intriguingly, reductions were most apparent among women who had not yet recorded a male birth, and less pronounced among women who already had sons.

Table 6. Fertility in Liaoning, based on boys born to married women ages 16-50 *sui*, Liaoning, 1749-1909.

	Incidence Rate Ratio	p-value
Period (Ref: 1749-1909)		
1786-1790	0.89	0.05
1810-1817	0.57	0.00
1837-1841	0.80	0.00
Location (Reference: North Liaoning)		
Central	1.06	0.00
South Central	1.04	0.00
South Central	1.02	0.29
Husband's Characteristics		
Official Position	1.22	0.00
Disabled	0.91	0.00
Diminutive Name	0.90	0.00
Number of Boys Already Born (Ref: 0)		
1	0.80	0.00
2	0.91	0.00
3+	1.04	0.17
N (person-years)	1011981	

Notes: Controls included fourth-order polynomials for age and year. To save space, the results for these controls are not included here.

Table 7. Differential fertility change during extended periods of cold summers, Liaoning, 1749-1909.

	1786-1790		1810-1817		1837-1841	
Variable	Incidence Rate Ratio	p-value	Incidence Rate Ratio	p-value	Incidence Rate Ratio	p-value
Period	1.00	0.98	0.49	0.00	0.78	0.00
Location *(Reference: North Liaoning*)						
Central	1.06	0.00	1.05	0.00	1.05	0.00
South Central	1.04	0.00	1.04	0.00	1.04	0.00
South	1.02	0.28	1.02	0.29	1.00	0.96
Husband's Characteristics						
Official Position	1.21	0.00	1.20	0.00	1.21	0.00
Disabled	0.91	0.00	0.92	0.00	0.90	0.00
Diminutive Name	0.90	0.00	0.90	0.00	0.90	0.00
Boys Already Born (*Reference: 0*)						
1	0.80	0.00	0.79	0.00	0.80	0.00
2	0.91	0.00	0.90	0.00	0.91	0.00
3+	1.04	0.14	1.02	0.37	1.04	0.12
Period *						
Location (*Reference: North Liaoning*)						
Central	0.95	0.51	1.43	0.00	1.07	0.26
South Central	0.85	0.15	1.21	0.00	1.11	0.10
South	0.90	0.41	0.90	0.31	1.45	0.00
Husband's Characteristics						
Official Position	1.22	0.05	1.28	0.04	1.11	0.39
Disabled	0.92	0.61	0.97	0.60	1.02	0.78
Diminutive Name	0.96	0.67	0.82	0.02	0.85	0.06
Boys Already Born (*Reference: 0*)						
1	0.97	0.72	1.07	0.24	0.95	0.34
2	0.55	0.01	1.35	0.00	0.99	0.88
3+	0.91	0.77	1.32	0.05	0.97	0.82

Notes: Controls included fourth-order polynomials for age and year.

Conclusion

The results here demonstrate that extended periods of adverse weather were associated with dramatic fluctuations not just mortality, but fertility. The nature of demographic responses appears to have varied. We examined changes in demographic behavior in three different periods characterized by cold summers, indicative of conditions associated with poor harvests, and found that one that coincided with the Tenmei famine in Japan was characterized by a mortality crisis, another that took place between 1810 and 1817 was characterized by a massive reduction in fertility, and another that coincided roughly but not exactly with the Tenpo famine in the 1830s did not exhibit a pronounced mortality or fertility response.

Patterns of responses revealed by our disaggregation by gender, age, socioeconomic status and other characteristics were a mixture of the expected and

unexpected. For the mortality crisis between 1783 and 1786, lower-status individuals such as the childless generally fared worse. However, individuals related to men who held official position, including their sons and their wives, and in adulthood, the officials themselves, also fared worse. At present we cannot explain this apparent disadvantage except to note that it appears to be another example of the relative complexity of the relationships between socioeconomic status and mortality in historical China. Whereas in almost all contemporary societies, socioeconomic status and mortality are inversely associated, previous studies of mortality in Liaoning, including Campbell and Lee (1996; 2006) and Lee and Campbell (1997) all reported that high-status males, including household heads, eldest sons, and men with position, experienced elevated mortality.

For the fertility trough between 1810 and 1817, patterns of differential responses were largely as expected, except that couples with more children appear to have changed their reproduction less than children with fewer children. This may reflect selectivity in the sense that couples with more children may have been better off, and thus more resistant to the adverse conditions that affected others. Again, in light of the magnitude of the climate shocks that triggered these fertility responses, we remain agnostic as to whether the responses reflected deliberate behavior, or were involuntary. While a role for deliberate limitation of fertility in historical Chinese population dynamics has been suggested (Lee and Wang 1999; Wang, Campbell, and Lee 2010), the magnitude of the shocks considered here were large enough to allow for involuntary responses, including reduced fecundity induced by malnutrition, spousal separation associated with short-term migration, and other mechanisms. Moreover, given the under-registration of deaths in infancy and early childhood, what we refer to as fertility reductions in this study may also have reflected increases in infant and early childhood mortality that reduced the numbers of children surviving long to be registered. Such mortality increases would need to have been truly massive to account for the extraordinary reduction in fertility apparent in the data between 1810 and 1817.

To our knowledge, this is the first study of a demographic disruption in China before the twentieth century to distinguish between mortality and fertility responses. Prior discussions of the role demographic crises in Chinese population dynamics before the twentieth century examine relationships of total population size to the frequency of famines, epidemics, and wars recorded in historical sources (Chu and Lee 1994; Ho 1959; Zhang et al. 2006; Zhao and Xie 1988). In our view, the longstanding reliance on changes in population size to infer demographic impacts of climatic and other disruption has been accompanied by an unspoken and largely untested assumption that reductions in population size were mostly due to increases in mortality, not reductions in fertility. The results here show that reductions in fertility, or increases in infant and child mortality indistinguishable in the data from reductions in fertility, may have been an important part of the demographic response to large exogenous shocks in historical China. Additional historical climate time series have recently become available, including estimates specifically for north China and possibly northeast China and Korea, and we look forward to replicating this analysis with these newly available time series.

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