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Cite this article: Pink KE, Quinlan RJ, Hin S. 2020 Famine-related mortality in early life and accelerated life histories in nineteenth-century Belgium. *Proc. R. Soc. B* **287**: 20201182.
<http://dx.doi.org/10.1098/rspb.2020.1182>

Received: 22 May 2020
Accepted: 12 October 2020

Subject Category:

Behaviour

Subject Areas:

behaviour, evolution, ecology

Keywords:

life-history theory, mortality, marriage behaviour, Belgium

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Electronic supplementary material is available online at <https://doi.org/10.6084/m9.figshare.c.5182431>.

Famine-related mortality in early life and accelerated life histories in nineteenth-century Belgium

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Density-dependent and extrinsic mortality are predicted to accelerate reproductive maturation. The first 5 years of life is a proposed sensitive period for life-history regulation. This study examines the ways in which local mortality during this sensitive period was related to subsequent marriage timing in nineteenth-century Belgium (*n* women = 11 892; *n* men = 14 140). Local mortality during the sensitive period was inversely associated with age at first marriage for men and women controlling for literacy, occupational status, population growth and migration. Cox regression indicated decreased time to marriage for women (HR = 1.661, 95% CI: 1.542–1.789) and men (HR = 1.327, 95% CI: 1.238–1.422) from high mortality municipalities. Rising population growth rates were associated with earlier marriage for men and women. Migration in general was associated with later marriage for men and women. Consistent with life-history predictions, harsh ecological conditions during early life such as famine coincided with earlier marriage.

1. Introduction

Recent studies indicate the effects of high mortality environments in early childhood on marriage and reproductive behaviour [1–3]. Life-history theory (LHT) predicts that harsh and uncertain living conditions accelerate maturation to compensate for the probability of fitness failure due to extrinsic risk such as predation and diseases [4] and density-dependent mortality (mortality at all ages is regulated by the density of the population e.g. [5–7]). The mortality risk is predicted to accelerate reproductive maturation and interbirth intervals [8] in what is sometimes referred to as ‘psychosocial acceleration’. In psychosocial acceleration, the first 5 to 7 years of life is a sensitive period shaping reproductive development. Previous work has shown that even *in utero* exposure to harsh environmental conditions such as epidemiological stress can affect life expectancy negatively and leads to reduced fertility (number of children) as well as an earlier onset of childbearing [9,10]. Effects of mortality exposure during childhood, however, appear to be complicated by multiple factors [11]: extrinsic (or unpredictable) and density-dependent mortality can influence biological maturation and reproductive decision-making throughout the life course [12,13], and energy availability and environmental predictability show substantial collinearity across human populations [14].

Apart from ecological circumstances, social and cultural norms also influence individuals’ marriage behaviour and timing. In nineteenth-century historical Europe, one of these norms was that reproduction was restricted to married individuals [15]. Lack of access to effective means to limit fertility, as well as a lack of willingness to use them (concept of ready, willing and able [16]), meant that fertility was not limited to a desired family size, and reproduction began soon after marriage. Therefore, there was a strong link between motherhood and matrimony where marriage marked the onset of sexual reproduction [17]. Despite

the considerable time-lag between biological maturation and age at first marriage, out of wedlock fertility was rather low in pre-modern Belgium [18]. Conceiving a child out of wedlock was seen as a mistake that could be avoided and was associated with social stigma [17]. Similar to marriage patterns in contemporary high-income populations, in the Belgian historical context timing of marriage and first birth were less dependent on physical maturation, and there was a time-lag between sexual maturity and marriage (and the onset of reproduction [19]).

2. Objectives

The current study uses nineteenth-century pre-transitional historical data from marriage certificates from the province of Flemish Brabant to investigate the impact of high mortality cues on male and female marriage behaviour. We aim to improve the understanding of life-history decisions around a cultural norm for relatively late marriage among historical and pre-transitional human populations. The nature of historical-demographic data does not allow us to identify precise mechanisms by which local environments influence long-term reproductive decision-making. Presumably, harsh environments cause less responsive parenting and reduced parental effort [20], which in turn induce accelerated life-history strategies including earlier maturation (age at menarche), sexual debut and first birth [8,21]. For this historical Belgium population, even relatively early marriages occurred well after any plausible onset of menarche; hence, marriage timing is likely under some conscious control influenced by psychological factors linked to an accelerated life-history trajectory. For example, increased impulsivity and delay discounting are two psychological factors associated with an accelerated life history that appear to be relevant for mating and family formation behaviours [4].

Life-history responses to crises may be complicated by conflicting psychological and physiological mechanisms associated with energy availability, causes of death and related effects on fertility [7,22,23]. Recent research suggests that the timing of puberty mediates subsequent reproductive behaviour, including sexual debut and first birth [8,24–26]. Other studies, in contrast, suggest that the clustering of life-history traits into neatly theorized ‘strategies’ rests on weak empirical ground [27–29]. Conscious reproductive decision-making may follow the logic of energy allocation in physical maturation, given evolved psychological mechanisms that track adaptively relevant environmental events. We suggest that psychosocial acceleration may influence reproductive decision-making independently of physiological development under particular socioecological constraints such as the ‘north-western European marriage pattern’. Based on LHT, we predict that municipality level mortality related to local famine [6,30] influences marriage timing in a context in which (i) marriage and physical maturation are largely decoupled, and (ii) marriage and childbearing are strongly linked to each other. Following psychosocial acceleration theory [21,31], we hypothesize that mortality rates at the municipality level in the first 5 years of life influence the timing of marriage even when marriage tends to follow puberty by many years. Marriage is predicted to occur earlier in municipalities experiencing high mortality, compared with municipalities that were little affected by famine and experienced comparatively low mortality. The

quasi-experimental setting of individuals growing up and living in high mortality settings during the first 5 years of life versus individuals living in low or intermediate mortality municipalities, and with exposure to shock-mortality conditions occurring well before the subsequent entry into the marriage market and the life event of marriage, provides improved opportunities to test LHT derived ideas linking environmental cues to reproductive scheduling.

3. Data and methods

(a) Study population and data collection

We examined associations between mortality and marriage timing in the context of an ongoing food crisis due to potato blight (*Phytophthora infestans*) in nineteenth-century Flanders. Data were collected from population censuses, statistical yearbooks and civil registers. The study population (n women = 11 892; n men = 14 140) was selected based on Belgium’s only digitized database of historical marriage certificates from the province of Flemish Brabant (then including the capital of Brussels) and covers people born throughout Belgium between 1841 and 1845. Individuals were distributed equally among the birth years (each birth cohort represents around 20% of the total sample). Mortality data were collected at the municipality level from population censuses and statistical yearbooks for the period 1841–1850. We obtained the mortality data as well as the number of marriages between 1841 and 1900 and the number of deaths between 1841 and 1850 from the Historical Databases of Local and Cadastral Statistics (LOKSTAT-POPPKAD), Ghent University, Quetelet Centre. We included women between 15 and 40 years at first marriage and men between 15 and 50 years at first marriage (subsequent marriages were filtered out of the dataset for this study). In the following subsections, first, the economic background is highlighted, and subsequently, covariates are introduced.

(b) Economic background

At the beginning of the nineteenth-century Belgium was the first country of continental Europe that experienced the industrial revolution. This process of industrialization took place against a background of small-scale, intensive agriculture practised by a dense rural population. Belgium’s industrialization was mainly based on coal, iron and textiles. The two linguistic regions of Flanders (Flemish speaking) and Wallonia (French speaking) followed different industrialization patterns [18]. The Walloon industry represented the economic backbone of the country until well into the twentieth century [32]. The Flemish provinces lagged behind, and it was only in 1937 that regional convergence in economic output was achieved—partly thanks to persistently low wages in Flanders [33].

The main driving force of Wallonia’s industrialization were the provinces of Hainaut and Liège with their coal mines, iron ore and manufacturing of machinery [34]. The provinces of Limburg, Namur and Luxembourg were mainly agricultural, and industrialization was largely absent. Since the Walloon textile industry operated with imported wool and cotton, it was independent of the local agriculture, and could expand more easily in comparison to the Flemish textile mills [18].

In the Flemish provinces of East and West Flanders the textile industry was tightly intertwined with local agriculture:

it relied on local flax production, and low wages made mechanization unattractive [32]. This situation was co-responsible for the collapse of the rural linen industry in the mid-nineteenth century: it could not compete against British mechanized cotton [18]. The potato and crop failure in the late 1840s intensified this crisis, and left one-quarter to one-half of the Flemish population in poverty [34]. The performance of the provinces of Antwerp and Brabant regarding industrialization was moderate. The port of Antwerp transformed into an international harbour and the city of Brussels featured a major machine manufacturing and chemical industry [35].

(c) Early-life mortality pressure, population density and population growth

In the 1840s and 1850s, the mean crude death rate (CDR) in Belgium was 23.4 [18]. However, municipality and provincial variation in CDRs was high—ranging, e.g. in 1841 from 3.7 to 57.1 and in 1847 from 0.0 to 100.2 per 1000 among municipalities in our dataset. Such high local variability is identified in LHT as potentially salient for understanding individual differences in mating strategies [6]. Two dimensions of mortality are thought to shape this process: overall mortality rates, and the ratio of juvenile to adult mortality [6,30]. In this paper, we focus on overall mortality rates that could be determined at the local municipality level for all 2538 Belgian municipalities for the period 1841–1850. Age-specific mortality rates were only available at higher levels of aggregation.

The population of Belgium grew between 0.7% and 1% per year from 1810 to 1850. But the agricultural production only grew around 0.6% [36]. To make matters worse, between 1846 and 1850 the country was faced with crop failure: harvests were only 40–60% of what they had been before. The potato blight started to affect the Belgian potato fields from mid-July 1845, much earlier than in other European countries, and destroyed around 87% of the 1845 harvest of Belgium's staple food. In the following years, the potato harvest was meagre and only one-third of the 'normal' potato harvest was reaped [36]. In addition to this, the rye harvest decreased by more than 50%, and the wheat harvest by 10% due to bad weather conditions in the year 1846. These crop failures created dramatic food shortages in late 1846 and during the first half of 1847, when only 125 litres of bread grains and potatoes were available per head in comparison to 375 litres per head in pre-crisis years [37]. The result was a subsistence crisis in a period of rapid population growth—a crisis that was characterized by mortality variation at the provincial level and the underlying municipality level [36]. The mortality rates of the provinces of East and West Flanders, for example, were 40% higher in the year 1847 than in the years 1841–1845. Most deaths during that time were not caused by starvation per se, but by nutrition-related diseases such as typhus [38]. To address the fact that individuals in our sample were exposed to the mortality peak in 1847 at different times of their childhood we included their birth years as a control variable. By doing so, we take into account the variance between birth cohorts not attributable to mortality differences.

In our analyses, we included the CDRs at the municipality level pertaining to the first 5 years of each individual's life, which are considered key developmental years in LHT [8,39]. The CDR is the number of deaths per 1000 inhabitants occurring among the population of a municipality during a given year.

Because our key interest is in the impact of exposure to extreme mortality conditions, we categorized CDRs in three different categories that led to approximately equal exposure group sizes: 1 = low (CDR < 20); 2 = middle (CDR between 20 and 32); 3 = high (CDR > 32). The cut-offs were calculated taking the mean CDR in the first 5 years $\pm$ one standard deviation.

Ideally, we would have liked to include an indicator of density-dependence in our models, since population density affects mortality rates as well. Including population density as a covariate alongside CDR would have enabled getting a sense of the relative effects of extrinsic and density-dependant mortality in our analyses. However, local population density turned out to be strongly associated with the CDR (grooms: $r = 0.64$; brides: $r = 0.69$). When CDR and population density entered models together, they caused substantial multicollinearity. Therefore, we included only the CDR in our models. CDR thus indicates density-dependent and extrinsic mortality, both of which predict accelerated maturation in LH models [7,22].

The population size of the investigated municipalities was on average 1649 citizens. As mentioned, Belgium's population doubled between 1750 and 1850, but not all areas grew evenly. Population growth patterns largely reflected patterns of industrialization. In general, the provinces of West Flanders, East Flanders, Limburg, Namur and Luxembourg had a negative population growth in the course of the nineteenth century. The industrial centres of Hainaut and Liège and the administrative and commercial centres of Brabant and Antwerp had a positive population growth [35]. The overall high population growth rates may also have influenced life-history behaviours. In a rapidly growing population, delaying reproduction results in a relative reduction in reproductive value because future reproduction is discounted as a function of population growth, expressed as $e^{-r(y-x)}$ where r is the rate of increase and $(y - x)$ is the delay in reproduction [40]. We included the average crude population growth at the municipality level during an individual's first 5 years of life to evaluate its effect on the timing of first marriage.

(d) Marriage characteristics

Belgian nineteenth-century marriage patterns were characterized by a culturally imposed time-lag seen among many European populations, and formed part of what is known as the 'north-western European marriage pattern' [41]. The mean age at first marriage was 30.5 years for men and 28.6 years for women in 1846–1856 [18]. There are various explanations for this high average age at first marriage such as certain age criteria, the need for consent by the parents in most cases and the prerequisite of economic independency of the newlyweds in order to be able to establish a new, independent neolocal household which took time [41,42]. In Belgium, the proportion of unmarried women was decreasing between 1846 and 1910 (see electronic supplementary material, A1). Marriage was a state that individuals desired, and that a large part of them entered into at one point in their lives. The proportion of unmarried 25–29-year-old women fell from 60% to 37% and for 40–45-year-old women from 22% to 17% during the abovementioned period [43].

(e) Socio-cultural and socio-economic heterogeneity

We examined the timing of marriage by municipality level mortality in the first 5 years of life for men and women

separately. Men and women were analysed separately due to substantial differences in their marriage behaviour that could obscure important gender interactions with other predictor variables.

Marriage behaviour differed between the north and the south of Belgium. The province of Hainaut had the highest marriage frequency during the nineteenth century, while the Flemish provinces of East and West Flanders as well as Limburg had the lowest [18]. Watkins [44] noted that areas which shared a language, a religion and a common culture showed similar marriage patterns. Belgium is divided by a language border (see electronic supplementary material, A2) and has a high degree of cultural heterogeneity, which provides a possible explanation for the different marriage patterns [34,44]. In our modelling process, this heterogeneity was captured through a theta-parameter.

Several studies have emphasized that higher occupational class is associated with later age at marriage [45,46]. In Belgium, a higher age at first marriage occurred among day labourers, servants and textile workers, while industrial working classes showed an earlier pattern of marriage [18,34]. We control for the effect of occupational class (HISCLASS) by including the profession of the groom and the bride in our models. Inadequate recording of women's occupations in documentary sources is very common in historical European contexts during the rise of separation of spheres for men and women and the rise of the 'male breadwinner norm' (in which women were preferably mothers and housewives if the head of the household could afford it). We therefore use the occupation of the father of the bride as a proxy for her socio-economic status in cases where the bride's occupation was missing. We categorized the HISCLASS variable in both models into four categories (1 = low; 2 = farmer; 3 = middle; 4 = high).

We further controlled for the ability of the groom and bride to sign the marriage certificate. Literacy is used as a proxy for education in historical-demographic studies [47,48]. People who were literate married later and therefore had a lower overall fertility [49].

(f) Migration

Marriage timing can be affected by migration. Such a link between migration and marriage has been observed for Belgium in the nineteenth-century context in studies on Antwerp, where migrants married later than locals, and the impact of migration on marriage timing depended on the nature of the migration, with mean age at first marriage lower for domestic migrants than for international migrants [50]. While in other historical contexts a connection between migration and marriage has also been established, the focus tends to be on rural-urban migration, probably because this type of migration is the most eye-catching type of migration in historical periods of urbanization. It is argued that, depending on the context, one of four underlying mechanisms can take precedence [51], producing either earlier marriage among migrants (mechanisms: economic advantage over stayers and/or lack of social control from family of origin that would dismiss certain candidates and delay marriage); no difference with locals (mechanism: adaptation) or later marriage among migrants (mechanism: need to settle in and establish new social networks delays marriage).

In Belgium, the provinces of Antwerp, Brabant, Liège and Hainaut were areas of in-migration, while in East and West

Flanders, Limburg, Namur and Luxemburg there was a lot of out-migration [18]. To control for the effect of migration, and get a better understanding of the impact different types of migration may have had on marriage timing, we included a variable in all models specifying whether an individual had migrated between birth and marriage, by comparing birthplace and marriage place with each other. We categorized the migration variable in five categories: 0 = non-migration; 1 = rural-rural migration; 2 = rural-urban migration; 3 = urban-rural migration; 4 = urban-urban migration. Of the 19 municipalities of the current Brussels Capital region only eight were urbanized at the time period under investigation: Brussel-Stad, Sint-Joost, Sint-Gillis, Elsene, Koekelberg, Anderlecht, Sint-Jans-Molenbeek and Schaarbeek. These eight municipalities were coded as urban, whereas the remaining 11 municipalities were coded as rural. Given findings on Antwerp [50], we expect migrants to marry later than locals. Because the impact of underlying mechanisms seems to be strongly context-dependent, and is not yet well understood [51], we do not formulate hypotheses beyond this general expectation.

(g) Statistical analysis

After performing descriptive analyses, Cox regression models were used to model time to first marriage and estimate the role of the factors described above in the timing of first marriage. In the results and discussion section, we focus on describing our main model that includes a theta-parameter to control for unobserved heterogeneity. The measured parameter effect sizes are thus adjusted for factors that might play a role but that we could not capture in precise parameters, such as the complex socio-cultural heterogeneities within and between provinces [52]. In the electronic supplementary material models not controlling for unobserved heterogeneity are included (see electronic supplementary material, A3 and A4). There, we also display models without all socio-economic variables (see electronic supplementary material, A5 and A6) ran to investigate the robustness of our main model.

4. Results

(a) Descriptive results

The CDR varied between the years 1841–1850 with a peak in 1847 and 1849. The mean CDR in the first 5 years among the municipalities in the brides' sample was 25.59 (s.d.: ± 5.34), and 25.31 (s.d.: ± 5.28) among the municipalities in the grooms' sample. In our sample, 18.11% of the female individuals and 15.76% of the male individuals were exposed to a high CDR in their surroundings (municipality level) during their early childhood. The mean age at first marriage among brides was 25.99 years (s.d.: ± 4.65 years) and 29.52 years among grooms (s.d.: ± 6.23 years). This is in line with the marriage pattern during this time period [18]. Male individuals who were exposed to high mortality surroundings during early childhood had a mean age at first marriage of 27.82 years (s.d.: ± 6.46 years), while men who lived in a low mortality context during the sensitive period had a mean age at first marriage of 30.65 years (s.d.: ± 6.35 years). Women who grew up in a high mortality environment had a mean age at first marriage of 24.08 years (s.d.: ± 4.44 years), while women who grew up in a low mortality

Figure 1. Kaplan–Meier curve of transition to marriage among women by CDR exposure (low, medium, high) during the first 5 years of life.

Figure 2. Kaplan–Meier curve of transition to marriage among men by CDR exposure (low, medium, high) during the first 5 years of life.

environment had a mean age at first marriage of 26.83 years (s.d.: ± 4.62 years).

In total, 55.41% of brides were capable of signing the marriage certificate, and 71.29% of grooms. The majority of the individuals in our sample were born in the province Flemish Brabant (88.32% in the brides' sample and 83.22% in the grooms' sample). In total, 64.05% of the brides were so-called 'stayers' (no migration) compared with 43.44% of grooms. Most individuals with a migration history had migrated from rural to rural settings (brides: 20.67%; grooms: 38.32%). Further descriptive statistics are covered in A7 and A8 of the electronic supplementary material.

(b) Cox regression results

Descriptive Kaplan–Meier curves suggest that there is a general negative association between high municipality level mortality in early childhood and age at first marriage among both men and women (see figures 1 and 2).

When CDR is high (black line in figures 1 and 2) female and male age at first marriage is pushed forward: the transition rate into marriage is higher, and at any age from about age 19 onwards, fewer men and women remain unmarried than among their counterparts in low-CDR environments.

This association is confirmed by the results of Cox regression which estimate the effect of municipality level

mortality in early childhood (0–5 years) on age at first marriage and are displayed in A9 and A10 of the electronic supplementary material.

Women who were exposed to high mortality during the sensitive period married significantly earlier than women who were not exposed to high mortality (hazard ratio (HR): 1.661***). Men who were exposed to high mortality during early childhood were significantly younger when they married (HR 1.327***). In both samples, population growth had a significant effect on the marriage behaviour of individuals. Individuals who grew up in an environment characterized by rapid population growth developed an earlier pattern of marriage (women: HR 1.024***; men: HR 1.039***). In both cases, the effect sizes were small.

Three out of the four migration categories (rural–rural migration, urban–rural migration and urban–urban migration) had a significant effect on marriage timing. In general, migrated individuals entered marriage later, although the effect size differs. Urban–rural migration had the most substantial effect among women (HR 0.486***). For men, the effect of urban–urban migration was most substantial (HR 0.712***).

Similar to previous research, we found that men from lower and middle occupational class married significantly earlier (HR 1.236***; HR 1.229***), than high occupational classes and farmers. For women with a low HISCLASS or women whose fathers had a low HISCLASS we observed a trend, although not significant, to marry earlier than their counterparts with a high occupational class.

The influence of birth year on the age at first marriage differed between the sexes. Whereas the birth year had no influence on marriage timing among men, we observed an earlier age at marriage for higher birth years among the women (HR 1.052***). The effect of birth year on age at marriage was much smaller, however, than the effect of exposure to high mortality.

Using literacy as a proxy for education revealed that both men and women who were literate married significantly later (HR grooms: 0.875***; HR brides: 0.861***) than their illiterate counterparts.

Finally, we noted that in both models, the likelihood ratio test of the model with the theta-parameter controlling for unobserved heterogeneity is significant, indicating that we cannot ignore correlation within provinces, nor significant differences in first marriage ages between provinces within Belgium. This is consistent with the literature on Belgium, where linguistic divides and economic heterogeneity across provinces coincided with differences in reproductive behaviour [4].

5. Discussion

Our results indicate that exposure to harsh environmental conditions such as famine and crop failure during the first 5 years of life are associated with accelerated life history, in this case earlier marriage. A link between exposure to high mortality and faster life history has been demonstrated for preindustrial and industrial populations [2,3,10,13]. Recent studies have also shown that earlier marriage is associated with exposure to harsh early childhood conditions [1]. Earlier works, however, did not address the effects of famine and crop failure on marriage behaviour in men and women. Furthermore, previous research paid little attention to the differences between men and women in their responses to

environmental stress. Our results suggest that age at first marriage, which was in part regulated by social conventions, responded to crisis-mortality cues during a sensitive period in infancy and early childhood. As predicted by life-history theory, both males and females with high mortality cues in childhood accelerated their life histories, as characterized by earlier marriages. Our findings are in line with previous studies that highlighted the impact of environmental factors during early childhood on developmental/psychological processes (e.g. [12,39,53]). One possible mechanism linking negative early experiences with faster life histories is a shift in the individual's time perspective from future-oriented to present-oriented [54], leading to behavioural adaptation: a 'life is here and now' attitude. Present-oriented individuals devalue the future; invest less in growth/maintenance; shift their resources towards early maturation/reproduction; and pursue high-risk strategies in favour of immediate and short-term gains [55,56]. An accelerated life-history strategy in a cultural setting where reproduction was restricted to married individuals could be an adaptive strategy to beat the odds of not reproducing at all in a harsh and unpredictable environment where life expectancy was reduced.

Occupational status was associated with the timing of marriage in similar ways for men and women. In general, individuals from a lower occupational class were younger at first marriage, although the trend was not significant among women. There are different explanations for the association between lower occupational class and earlier marriage among men especially. First, the general pattern requiring more education or training for relatively high-status occupations [57] may have delayed marriage for higher status men. Furthermore, men often needed to wait for an inheritance from the ascending generation to establish a socially viable marriage [15]. Third, due to economic development, there were increased opportunities for employment among the lower occupational classes that, for them, provided the means to start a family earlier [58]. Literacy was associated with delays in marriage for both men and women, a pattern that is commonly seen in studies of fertility in low-income and developing populations [45].

In our sample, migration was associated with significant delays in marriage for women and men. This pattern might be explained by the social exclusion of migrants, as suggested in earlier work with similar findings [50]. The effects were strongest for men and women migrating from urban to rural settings. Why this is remains a matter of speculation, but we suggest it might have been extra difficult for people coming from 'the big city' to find a partner in closely knit small rural communities because of high social control, and because nearby relatives of potential partners still had a substantial say in the partner choices of their children [1,58].

The impact of population growth rates is an understudied aspect of life-history strategies. In rapidly growing populations, future reproduction is discounted as a function of population growth. The significant effects in our study of population growth on both sexes' age at first marriage might be understood in the light of the growing competition in the marriage market. In both of our models, the effect size of total population growth is relatively small.

One important limitation of this study is that people who never married are excluded from the analysis due to limitations of the available dataset, which consists exclusively of marriage records. The inclusion of never-married individuals

as censored cases could reduce hazard ratios reported here. However, this would require nationwide collection of linked birth and death records, which was not feasible in the context of this study. It is possible that the decision to never marry was also influenced by exposure to high mortality in early life during the crisis years.

A second limitation is that the CDR does not allow us to assess the effects of age-specific mortality on age at first marriage. LH models sometimes specify adult versus juvenile mortality as important influences on reproductive behaviour [22]. We assume that variation in mortality related to crop failure likely had the strongest effect on children and elderly people. Furthermore, though formal life-history models identify age-specific mortality patterns, we wonder whether human environmental perception is fine-tuned enough to respond to age-specific rather than general mortality trends such as CDR.

Third, high mortality environments may also invoke social processes that induce earlier marriage, independently of biological processes. For example, Voland & Willführ [1] demonstrated on the basis of family reconstitution data that paternal loss at a time when the child was of marriageable or near marriageable age accelerated the transition to marriage in pre-modern societies. This pattern resulted from the fact that the death of the household head generated income shocks, making it more difficult for remaining members to maintain the whole household. Therefore, the decision to marry was often shifted forward for opportunistic reasons. Disentangling the influence of social and biological factors and processes with the historical datasets we dispose of is beyond reach: this would require contextually rich longitudinal data that allow for tracing the socio-economic living conditions of households across time. This is a limitation of the current study. However, in our sample there is a longer time-lag between exposure to mortality and marriage, leaving more room for heterogeneity in subsequent socio-economic life trajectories. Moreover, the study of Voland & Willführ deals with exposure to mortality within the household, while in our study exposure to mortality is at the local level. For Belgium, at a more aggregate level, we see no indications that social or cultural responses to high mortality were the main drivers behind earlier marriage in our sample. At least, that is, the fact that during the overall period 1846–1919, the provinces of East and West Flanders, which were the provinces hit hardest by the crisis, remained the provinces with the lowest marriage frequency (see marriage timing section and A7 and A8 of the electronic supplementary material), suggests that the mortality crisis did not create regionalized social pressures towards frequent and early marriage.

Fourthly, varying cohort size may change marriage market competition: demographic theory and previous research suggest that decreasing cohort size may lead to decreasing competition for spouses and lower age at first marriage [59]. Yet due to data availability limitations, we were unable to include cohort size as a control variable in our modelling, nor able to include birth years before and after those affected by the famine. We cannot, therefore, exclude that our outcomes were affected by a decrease in cohort size of famine-affected cohorts entering the marriage market. However, we were able to verify cohort sizes of adults for census years at the country level. These suggest that near marriage age, the famine-affected cohorts were not

smaller overall than preceding cohorts and hence competition on the marriage market was not lower overall for the cohorts 1841–1845 (see electronic supplementary material, A11). However, we cannot exclude that, at the municipal level, variations in cohort size could have impacted upon local marriage market dynamics and played a role in marriage age outcomes.

In sum, a growing body of research on historical populations suggests an important role of mortality in shaping human reproductive strategies. Our study, which made use of a quasi-experimental design, suggests that high mortality cues are associated with earlier transition into marriage in a context where marriage marked the onset of sexual reproduction. This finding was robust to controls for different socio-cultural factors. It provides further support to the hypothesis that individuals adapt their life histories according to LHT predictions by shifting their timing preferences. At the same time, the nature of the data used for this study leave, as described above, opens questions that we hope to see addressed in future work.

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Ethics. Data were drawn from nineteenth-century marriage certificates from the province of Flemish Brabant as well as statistical year books and therefore do not include any living individuals.

Data accessibility. Data available from the Dryad Digital Repository: <https://doi.org/10.5061/dryad.hmgqnk9f0> [60].

Authors' contributions. K.E.P. and S.H. conceived and designed the study, and prepared the dataset. K.E.P. carried out the analyses. R.J.Q. provided LHT expertise and input to refine the study design. K.E.P. and S.H. interpreted analyses. K.E.P., S.H., and R.J.Q. drafted the manuscript. All authors gave final approval to the publication.

Competing interests. The authors declare that they have no competing interests.

Funding. K.E.P. acknowledges financial support from KU Leuven Concerted Research Action GOA ZKC6394 ('New approaches to the social dynamics of long-term fertility change'). S.H. received funding from the BELSPO BRAIN-project (BR/121/A3/GWB).

Acknowledgements. The authors thank the volunteers at the Leuven historical archives, in particular Eddy Put and Patrick Trio; Alessia Ruggeri for her valuable contribution during data preparation; Sven Vrielinck for data preparation of the mortality data, figures on marriage proportion and mortality distribution; and Koenraad Matthys for general support and for providing the dataset.

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