THE RELATIONSHIP BETWEEN LATE CHILDBEARING AND POST-REPRODUCTIVE LONGEVITY: THE CASE OF HISTORICAL GERMANY

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In today's developed countries, women are increasingly delaying their childbearing, with unknown consequences for their health and longevity. Public discourse and medical procedures are often focused on the pregnancy and the fetus, rather than on the pregnant women who bear children late. Numerous tests are performed on women over 35 who become pregnant to detect various medical conditions in their to-be-born children. Also, some pregnant women over 35 with a designated risky pregnancy are given various hormonal treatments to prevent spontaneous abortions. These common medical procedures for pregnant women over 35 are not designed to manage and protect women's overall health and longevity, but rather their pregnancies and fetuses. Moreover, maintaining a pregnancy through medical procedures might negatively affect women's longevity. In this paper we focus on the relationship between late childbearing and post-reproductive longevity. By comparing the longevity of women who had their last pregnancy late versus not late, our findings will be relevant to contemporary society.

Although the relationship between childbearing and longevity has long been studied (see Dorn & McDowell, 1939; Freeman, 1935, Bell, 1918) and continues to be studied (see Alter, Dribe & van Poppel, 2007; Smith, Mineau & Bean, 2002, Gavrilov & Gavrilova, 1999), there is no conclusive evidence regarding the direction of the relationship or even whether childbearing and longevity are related at all. As described in Alter, Dribe and van Poppel (2007), (1) some view childbirth and childrearing as stressful experiences with long-lasting consequences for the mother's health, (2) others see childbearing as an indicator of good health, implying that women with later births will be more resistant to disease at later ages, and yet (3) others suggest that human evolution resulted in a genetic trade-off between reproduction and longevity. Moreover, the results from empirical studies are at least as diverse and contradictory as the theoretical perspectives speculating on the relationship between childbearing and longevity. For instance, Smith, Mineau and Bean (2002) found that in general women who had fewer children as well as those who were fertile late had lower rates of mortality. In contrast, Cooper (2002) found that late childbearing increased the risk of dying. Yet, Alter, Dribe and van Poppel (2007) have found no relationship between age at last birth and longevity, and mixed results on the relationship between the number of children ever born and post-reproductive longevity.

Most studies linking fertility with longevity have examined the relationship between parity (the number of children ever born) and survivorship, rather than the specific impact of the age at last birth on longevity, the focus of this study. In this paper we examine the impact of "age at last birth" on longevity, as one of the aspects defining women's fertility. Childbearing could be seen as a process composed of at least three separate parts: the age at first birth, the number of children ever born, and the age at last birth. We believe "age at last birth" is an important component of fertility, but it should always be examined together with (controlling for) the other two essential components defining women's fertility, number of children born and the age at the start of childbearing.

The few studies we have found examining the specific link between "age at last birth" and post-reproductive longevity are quite contradictory, and we believe our study could add an important piece of evidence to this literature. Previous studies (Alter, Dribe & van Poppel , 2007; Smith, Mineau & Bean, 2002; Doblhammer, 2000) have used different populations (e.g., from

England, Austria, Belgium, U.S., Holland, and France) in various periods and slightly different models to test the relationship between fertility and longevity, which partially explains their diverse results. Our study uses a dataset from a historical population of six German villages with complete fertility histories of 3024 married women who lived at least until age 50 to test the link between age at last birth and post-reproductive longevity. It includes information about all people who were born and died in one of the study villages, and who are a typical population for rural Western Europe between seventeenth and nineteenth century. Although not a random sample of Europe or either rural Germany in any rigorous sense, these villages represent a considerable range of demographic conditions, indicated by inter-village differences in religious affiliations, marital fertility, child mortality, age at first marriage, occupational distributions and inheritance systems (Knodel, 1988). This source of data is also one of the most accurate and complete available, due to the strict check systems imposed to those who compiled these data unique to Germany (Knodel, 1988). Moreover, absence of modern medical care, which could mediate the effect of fertility on longevity, characterizes most of our study period. Combined with the completeness and accuracy of the data, this later feature makes our data a particularly superior source for studying the effect of fertility on longevity. Some recent previous studies (e.g., Doblhammer, 2000, Cooper et al, 2000) used relatively simple statistical methods (e.g, logistic regression), while others used less common populations (e.g., the predominantly Mormon population in Smith, Mineau & Bean, 2002, or white college educated US women in the pre-war era in Cooper et al, 2000). Our study uses a typical population and advanced statistical techniques (frailty models) to account for unobserved factors that could impact longevity, in addition to a set of important controls that were missing in many studies. Furthermore, many previous studies (e.g, Alter, Dribe & van Poppel, 2007) have assumed a linear relationship between the age at last birth and the hazard of dying during the post-reproductive years, and this might explain why they have found no relationship between the two. Our study will explore different model specifications, without an a priori assumption of linearity.

Hypotheses

"Maternal Depletion" Perspective

One of the theoretical perspectives pertaining to the relationship between the late age at last birth and post-reproductive longevity is the "maternal depletion" model. The phrase "Maternal Depletion Syndrome" was first popularized by Jelliffe and Maddocks (1964) to describe the negative energy balance and/or micronutrient deficiencies resulting from the energetic burden of frequent reproductive cycling (one cycle being conception, pregnancy, lactation/postpartum) combined with under-nutrition and overexertion, and its impact on a woman's health and nutritional status and those of her offspring. Many later studies have used "maternal depletion" to describe the negative impact of repeated childbearing on women's bodies in terms of poor nutrition, greater exposure to disease, and other physical and emotional stress. Although this term has been used in regard to repeated childbearing, we can extend the term to refer to the nutritional depletion caused by births that occur at late ages, when women are more likely to experience mineral deficiencies. Thus, from this perspective, we expect women who give birth at late ages to experience more costs associated with childbearing, such as more rapid demineralization, overexertion, greater exposure to disease, as well as obstetrical complications and miscarriages with long lasting health consequences.

Many studies examining the relationship between giving birth at late ages and post-reproductive longevity have either found a positive relationship between the two or no relationship, thus invalidating the maternal depletion hypothesis (e.g., Alter, Dribe & van Poppel

, 2007; Smith, Mineau & Bean, 2002; Doblhammer, 2000). We have located two studies that found that late childbearing decreases the chance of post-reproductive survival. First, Doblhammer and Vaupel (1998) found in a large study of Austrian women, that the risk of mortality from breast cancer was significantly increased for women who gave birth over the age of 40, although their mortality risk from circulatory diseases was significantly reduced. Second, Cooper et al (2000) found in a medical study of 826 college-educated women from the Midwestern United States followed from 1935 to 1990, that those who gave birth after the age of 40 had a post-reproductive mortality risk more than twice as large as those who had their last birth in their early thirties. Despite their important findings, these two studies do not offer a definite answer on the relationship examined in this paper. While Doblhammer and Vaupel (1998) could not include in their analysis all women who gave birth after 40 because their data only recorded the age at birth until up to the fourth child, Cooper et al (2000) study is limited by only including college-educated women.

"Slower Aging" Perspective

Another useful perspective for understanding the relationship between the late age at last birth and post-reproductive longevity is "aging at slower pace." Doblhammer (2000) suggests that the reason she found an overall higher longevity for women who gave birth after the age of 40 in both of her samples (from Austria and from England and Wales) is that the age of 40 is a biological marker that (1) these women had always aged at slower pace, and that (2) their menopause occurred comparatively late. Furthermore, Snowdon et al. (1989, 1990, as cited by Doblhammer, 2000) have found that the mortality risk for women who had their natural menopause before the age of 40 is nearly twice as high as for those who experience menopause between 50 and 54 years of age. This finding was also confirmed by Cooper et al (2000) study, which found an increased mortality risk for women who had their menopause before the age of 40.

This perspective suggests that women who give birth at late ages will have higher longevity, a fact confirmed by some studies (e.g., Smith, Mineau & Bean, 2002; Doblhammer, 2000) and our alternative hypothesis in this paper. The mechanisms leading to late versus earlier age at menopause are not known, but two possibilities include healthy behavior and genetic makeup. While the genetic makeup is a matter of selection (see the next subsection), healthy behavior has been shown to have an impact on childbearing. For example, smoking is one factor that has been established to decrease the age at menopause (McKinlay at all, 1985, as cited by Doblhammer, 2000).

The Selection & Social Support Perspectives

Alter, Dribe and van Poppel (2007) suggest that the association between fertility and post-reproductive longevity may be confounded by correlations with other factors related to childbearing and longevity. For instance, women in poor health may be less able to conceive at later ages but also more likely to live shorter lives compared to women in good health. Thus poor health determines both longevity and fertility, and not fertility longevity or vice versa. Also, the genetic makeup may influence both the age at menopause and longevity, so it is possible no direct link between childbearing and longevity exists.

Finally, social factors might play a role. For example, Menken, Duffy & Kuhn (2003) suggest that women in their later years may benefit more from support from younger children than from older children. This differential support is likely due to different life stages of children, with middle aged offspring being the least likely to offer support because of their responsibilities to their own dependent children.

Although the above hypotheses are competing, it is worth noting that they do not work in isolation to each other. Several competing mechanisms may simultaneously affect women. For instance, late age at menopause may indicate youthfulness (and is consequently related to a longer life), but a late birth may also negatively affect women's bodies. Both of these mechanisms are mediated by life style factors such as nutrition, stress, social support and access to healthcare. To illustrate how these competing mechanisms may simultaneously women, consider a hypothetical example of two women A and B, who are otherwise identical except age at menopause and age at last birth. In the first scenario, A has the same age at menopause as B, but B had her last birth later than A. In this case we expect A to live longer than B because the two women had the same age at menopause (and therefore are equally "young"), but B was "more depleted" by a later birth. In the second scenario, B still had her last birth later than A, but she had also had her menopause later. Thus A had her last birth earlier than B because she was not physiologically able to have a child as late as B did. In this case we expect B to live longer than A, or at least longer than she would have lived in the first instance. This example is an oversimplification done for illustrative purposes, although its scenarios are supported by at least one study that found opposite effects of late age at menopause and late childbirth on longevity (Cooper et al , 2000). Finally, we believe we cannot place in the same category women with identical ages at last birth who vary drastically in the number of children they bear in their lifetime. Thus, "age at last birth" should always be studied together with other aspects characterizing women's fertility such as the number of children ever born and age at the start of childbearing.

DATA AND METHODS

Sample

In this study, we are using a sample of life histories coming from parish registers data from six German villages collected by Knodel (1988) covering mostly eighteenth and nineteenth centuries, although our earliest subject was born in late sixteenth century. Knodel (1988) collected data on 14 German villages, but only for six of these villages (Brausen, Kappel, Massenhausen, Middells, Öschelbronn and Rust) data was coded for all the people in the village. Only pre-selected couples were coded for the remainder. To minimize the possible severe bias caused by a non-random selection of couples, we decided to focus in our study only on the six villages for which the data is complete. An additional advantage of focusing on these six villages is that (only) these data have family of origin identification numbers, thus allowing us to run household/family frailty models accounting for common unobserved environmental and genetic factors affecting the mortality of those in the study. As Knodel (1988) has shown, these villages represent a considerable range of demographic conditions and they are quite diverse geographically, covering the north, center and south of Germany (see map in figure 1). As seen in figure 1, two villages are in Waldeck region, two in Baden region, one in East Friesland region and one in Württemberg. In our analysis, we will code the villages located in the center and north of Germany as being in the north, and the rest of villages in the south.

Although the database created by Knodel (1988) contained information on all the people in the village, for the purposes of this study we only include in our analysis women who lived to be 50 years of age and were born and died in one of the study villages. Thus, our sample is biased toward long-lived and stationary women, although the bias is not as severe as in other sixteenth to nineteenth century populations. Because we have information about all the people in the village, we were able to calculate the percent of women who did not survive to age 50 (about 25%). We included only those who survive until 50 because we wanted to capture all women eligible for a late birth, and we wanted to focus on mortality caused by other factors than childbirth. Furthermore, our analysis sample of women who survived past 50 had almost identical characteristics to that of all women, as could be seen in table 1. The only substantial difference we observed between the two samples is that the all women sample had a much smaller percent of widows than the survivors past 50 had. This seemed surprising, as the widows have been found to have an increased risk of dying compared to married women (see Alter, Dribe & van Poppel , 2007). However, since our marital status variable is time-varying, we interpret this finding as simply the natural increase in the likelihood of husbands' dying as the time passes. Thus, when younger women are included in the sample they are more likely to have their husbands alive than a sample of older women only (survivors past age 50).

Variables

Table 2 presents a description of the variables we used in our study. Our dependent variable is measured as the duration in days/ years (when discussing results) from women's fiftieth' birthday until the day they die. Our main predictor is "age at last birth." We have explored several forms of this variable (as a series of dummies accounting for age intervals, as a continuous variables, as a polynomial term, and as one dummy separating women by a specific cut off point), and found that the largest difference in our multivariate models was given when we use it as a dummy of before or after the age of 38. Thus, we only show "age at last birth" in a dummy form, although results with other forms are available upon request.

Most studies that examined the relationship between fertility and longevity have considered the variable "children ever born," with mixed results for the direction of the relationship. For example, several recent studies (Doblhammer & Oeppen, 2002, Smith, Mineau & Bean, 2002 and Dribe, 2004) have found a negative association between children ever born and post-reproductive longevity. Other studies (e.g., Gavrilov & Gavrilova, 1999) have failed to find such relationship. Furthermore, several studies (e.g., Doblhammer, 2000) found a “U” shape relationship between parity and longevity: nulliparous, women with one child and women with high parity have an increased risk of post-reproductive mortality compared to women with 2-4 children. We have included “children ever born” in almost all our models since we believe this variable is one of the most important controls to be included in any model studying the effect of “age at last birth” on longevity for reasons mentioned earlier in this paper.

Age at first birth has been shown by several studies (Smith, Mineau & Bean, 2002; Doblhammer, 2000) to be negatively associated with post-reproductive longevity, and we include it in our study as another important control. Marital status is also controlled for in our analysis, as previous studies (e.g., Alter, Dribe and van Poppel, 2007) have found that the risk of dying was significantly higher for widows, and especially for young widows, compared to married women. SES is an important predictor of most social and demographic phenomena including mortality (see Smith, Mineau and Bean, 2002), and it is therefore one of our covariates. Our SES measure is represented by a series of dummy variables indicating husband’s occupation with the reference category being that of “farmer,” one of the most typical occupational categories in our study villages. We also include in our models a dummy variable for place of residence (north/south) and for religion, because distinct patterns related to marriage, childbearing, breastfeeding and birth spacing were found between the villages in the southern and northern Germany, and between Protestants and Catholics in our study period (Appendix C, Knodel, 1988). Finally, we have considered including in our models controls for various periods of time, as we assumed large differences affecting both fertility behavior and longevity might characterize women living in different times. Nevertheless, since we only include in our analysis long-lived women, we are mostly concerned with how fertility changed over time. At closer inspection we discovered that the only period control that makes a difference in some of our models is a dummy indicating the period before and after 1850, as well as its interaction with "age at last birth." Table 3 shows that the average age at last birth remained almost unchanged over 250 years in our study preceding the year 1850. Only after this year we start seeing some slight declines, although only consistently for Catholics. As Knodel (1988) shows, this result is consistent with other studies, which have shown that for most of the period covered by our study, rural women in Germany displayed natural fertility behavior, although some villages were faster than others to show signs of fertility limitation, as the time progressed.

Models

To estimate the effect of "age at last birth" on the hazard of dying, we estimated Gompertz models with an inverse Gaussian shared frailty, taking the following form:

$$h\,(t_{ij}|\, x_{ij,}\, \alpha_i) \;= \alpha_i \exp(\gamma\, t_{ij}) \exp\,(\beta_0 + x_{ij}\beta_x)$$

The Gompertz distribution is an old distribution that has been extensively used by medical researchers and biologists modeling mortality data (Cleves, Gould & Gutirrez, 2004). This distribution is suitable for modeling data with monotone hazard rates that either increase or decrease exponentially with time. Since we model mortality after the age of 50, we expect the hazard rates to increase exponentially with time, and theoretically Gompertz seems the most suitable. We have run both semi parametric (Cox proportional hazard) models and parametric models suitable for studying longevity (Weibul and Gompertz) and found the results to be extremely similar. However, Gompertz models had the best fit, as indicated by both the log likelihood and by Akaike Information Criterion (AIC). Table A in appendix presents AIC statistics for Cox, Gompertz and Weibul models.

In the above formula, $h\ (t_{ij}|\ x_{ij,}\ \alpha_i)$ is the hazard rate at time t_{ij} for an individual with characteristics x_{ij} and frailty α_i. The ancillary parameter γ controls the shape of baseline hazard. If γ is positive, the hazard function increases with time; if γ is negative, the hazard decreases with time; if γ = 0, the hazard function does not vary with time, which reduces the model to an exponential model. α_i is a random effects term that enters multiplicatively on the hazard function to indicate the shared frailties (the common unobserved genetic and environmental factors that may impact longevity) among women from the same family (sisters). The index *i* denotes the group or the family in our case ($i = 1, ..., n$), and *j* denotes the observation within group or the individual woman, $j = 1, ..., n_i$. The frailties, α_i, are thus shared within each family and are assumed to follow either a gamma or inverse-Gaussian distribution and are assumed to have unit mean and variance θ. The frailty variance, θ, is estimated from the data and measures the variability of the frailty across groups. A likelihood-ratio test of H_o: $\theta = 0$ indicates whether the frailty effect is significant, or whether we have significant heterogeneity among families in this population. We present the results assuming an inverse Gaussian shared frailty, but the results assuming a gamma distributed shared frailty are surprisingly similar in our case, and they are available upon request.

RESULTS

Descriptive

The median survival time for women in our study is 18.63 years after the age of 50 (thus the median woman survived to 50 + 18.63= 68.63 years of age), and the oldest woman survived 47.43 years after the age of 50, making her almost a centenarian. The median survival time differs significantly by religion, region and marital status in the overall sample, as seen in figure 2. Catholics have a significantly higher hazard of dying compared to Protestants, and Jewish women. Widows and those living in the south have a significantly higher hazard of dying compared to married women, and those living in the north respectively. Based on figure 2, only towards the very late ages an effect of age at last birth appears: those who had their last child after the age of 38 have a higher risk of drying. This effect is not statistically significant.

As table 1 shows, the average age at last birth is 38.18, and the average age at first birth is 26. On average, women in this sample gave birth to 5.8 children, and experienced the death of two children. Fifty two percent of women were Catholic, 18 percent southern Protestant, 30 percent northern Protestants and less than one percent Jewish. Seventy percent lived in the south. The modal category for occupation was that of farmer (33 percent), although there are substantial numbers of artisans and craftsmen (25 percent), of laborers (26 percent), and of a residual category containing temporary and unknown occupations (13.24). Although by today's standards most of the people in our sample were poor, Knodel (1988) shows that farmers were a relatively well-off category together with the artisans and craftsmen. We can think of these categories as today's middle class. In contrast the laborers were the poor of the society, many of them being agricultural laborers who did not own land. Finally the residual category represents the poorest poor of the community, people without stable jobs and who owned almost nothing.

Inferential

Our first model in table 4 shows that age at last birth is not significant in the overall sample by itself. This was not a surprising finding for us, and we think this result is quite irrelevant, in a miss-specified model without controls for other important covariates. In our second model, we add all the women-specific characteristics together with the random effects term controlling for family level unobserved environmental and genetic factors. In this model, “age at last birth” is positively and significantly related to the hazard of dying. We found that at age 50 (at time t_0), women who had their last birth after the age of 38 had 17 percent higher hazard of dying compared to those who finished their childbearing prior to age 38. When we add period and the interaction of age at last birth with period in model 3 (additions which significantly improved the fit of the model), the effect of age at last birth is larger and significant, indicating a 19 percent higher hazard of dying for women who had their last birth after the age of 38 compared to those who finished childbearing earlier. We will focus on model 3 in all our subsequent discussions, as it is our best-fit model (our fourth model adding one more insignificant interaction between age at last birth and “children ever born” has a worse fit than model 3).

The hazard ratios in frailty models have the interpretation at time t_0 only (at age 50 in our case). After that, the effects of covariate differences become muted as the more frail experience failure and so are removed from the surviving population. The frailty effect is quite large and significant in model 3, indicating significant heterogeneity among families in this population. However, compared to the frailty effect in model 1 and 2, in model 3 this effect is smaller, indicating a larger explanatory power of our covariates.

In frailty models there is also a distinction between the hazard individuals face and the population hazard that arises by averaging over all the survivors. Figure 3 graphs the individual and population hazards by age at last birth. The individual hazard represents the hazard for women in a family with unit frailty (mean frailty). For women with average frailty (individual hazard graph), the hazard of dying is very low and indistinguishable between those who had their last birth before and after the age of 38 until about the age of 70 (20 years after t_0=age 50). Then the hazard is higher among those who had their last birth after the age of 38, although for both groups of women the hazard increases exponentially after age 70 in a similar fashion. The population hazard is surprisingly similar with the individual hazard in that the differences between women who had their last child before and after 38 is larger at later ages. However, in contrast with individual hazard, the population hazard of women who had their last birth after 38 is higher than that of their counterparts from the start (age 50) and remains higher over the whole duration.

We found significant effects for all of our covariates, except age at first birth. All effects are interpreted at age 50. We found that women who bore many children had a significantly reduced risk of dying, while those who had children dying, had a significantly higher risk of dying. Each child born decreases the risk of dying by 4 percent, while each dead child increases the risk of dying by 5 percent. Widows have a 16 percent higher risk of dying compared to married women. Our largest effect is that of religion and region, with northern Protestants having a 44 percent lower risk and Jewish women having 70 percent lower risk of dying compared to Catholics. Southern Protestants on the other hand, had a 19 percent higher risk of dying compared to Catholics. Among the occupational groups, the two poorest groups (laborers and undetermined) had a significantly higher risk of dying compared to the “middle class” (farmers), with the other groups being no different from farmers. Period had a significant effect, with women born after 1850 having a 32 percent lower risk of dying compared to women born before 1850. However, the interaction between age at last birth and period was insignificant, indicating that the effect of age at last birth is no different across the two periods.

We compared our best fit shared frailty model (model 3) with model 5 that is identical with model 3 except we allow for women-specific unobserved heterogeneity rather than shared among families. The unshared frailty controls for factors that are individual-specific and are not shared by families such as birth order, various disabilities and birth defects, or even physical features such as tallness or beauty which could influence marriage prospects, self-esteem and longevity in myriad ways. Model 5 is surprisingly similar with model 3, in that all variables in our model except the interactive term have the same direction, significance levels and similar magnitude with those in model 3. The unshared frailty effect is much smaller than the shared frailty effect, but still significant. The interactive term between age at last birth and period (now significant) indicates a different effect of age at last birth before and after 1850. The effect of age at last birth for women born before 1850 (displaying natural fertility behavior) is equal to the main effect of "age at last birth." Women born before 1850, who had their last birth after the age of 38, had a 20 percent higher hazard of dying compared to those who had their last birth before this age. However, for women born after 1850 (displaying fertility limitation behavior), the effect is not significant. Thus, in the unshared frailty model we find a positive significant effect of age at last birth on the hazard of dying only for women born before 1850 and displaying natural fertility behavior.

INTEPRETATION

We started out with two main alternative theories, the maternal depletion hypothesis, and the slower aging perspective. Our results have shown support for the maternal depletion model and no support for the slower aging perspective. While later age at menopause may indicate youthfulness, the birth of a child seems to be indeed a high toll on women's bodies, especially if it occurs after the age of 38. In our study, women who gave a birth after the age of 38 have about 20 percent higher post-reproductive hazard of dying compared to those who finished their childbearing before the age of 38. This effect was stronger in a natural fertility population, when age at last birth was not necessarily a conscious decision. While our shared frailty model, indicated the same effect before and after 1850, our unshared frailty model indicated no effect of age at last birth for women born after 1850. As suggested in the beginning of our paper we believe access to medical care, good nutrition and healthy life style could mediate the effect of age at last birth on longevity. Women born after 1850, giving birth during late nineteenth and early twentieth century, may not be as affected by a late birth as their earlier born counterparts because they had access to medical care, social benefits and better nutrition. Thus the depletion and overexertion caused by a late birth might be counteracted by access to better nutrition and modern medical care. Our sample was particularly advantageous for testing the relationship between fertility and longevity because it allowed us to isolate this effect in a context without access to modern medical care (from the sixteenth century until about 1850), which might intervene to moderate, attenuate or even eliminate this effect. Moreover, our models also controlled for unobserved characteristics affecting families and individual women such as plagues, famine, various cultural practices, genetic factors, birth defects, physical attractiveness, and innate health, which could all affect women's mortality. We found family frailty effects to be much stronger than individual frailties. This was not surprising as in our population the lives were strongly determined by their local communities (see Knodel 1988). Our results thus confirm the positive relationship between "age at last birth" and the risk of dying found by Cooper et al (2000), but also improve upon these findings, as we show this relationship in a larger, more typical and much more diverse sample.

Although our main focus was on "age at last birth", we will end our discussion by shortly commenting on our other interesting findings. One finding contrasting with previous studies was that the more children a woman had the longer she lived. We believe this effect is due to the fact that fertility behavior and marriage patterns were strongly connected with economic wealth in these communities. Concern about overpopulation, the growth of pauperism and the perception of the poor as posing a potential threat of revolution, resulted in the enactment of restrictive legislation on marriage. These restrictions on marriage required a couple wishing to marry to produce sufficient evidence of having sufficient wealth or property, a secure income, or assured stable employment opportunities in order to allay doubts about their ability to support children (Knodel, 1988). These restrictions may have resulted in the tendency for poorer residents to have fewer children. Thus, what may seem like a protective effect of "children ever born" is actually a matter of selection, resulting from the tendency of wealthier couples to produce more children but also to live longer due to other factors (e.g., better nutrition, lower levels of stress). Another possible explanation may be related to other aspects of fertility behavior, such as breastfeeding. Knodel (1988) shows that women living in the north breastfed for very long periods, while those in the south either breastfed for very short or not at all. While breastfeeding done in moderation may have a protective effect (e.g. it protects women against breast cancer, American Institute for Cancer Research Report 2008), if women have many children that they breastfeed for very long, it may result in higher risk of mortality due to "maternal depletion." We have conducted some subsequent analyses (not shown) and found an interaction effect between "north" and "children ever born." Although in general women in the north had a much lower hazard of dying compared to those in the south, if they bore many children they had a much higher hazard of dying than if they had fewer children. This is consistent with the breast-feeding hypothesis. Since women in the north breastfed for long they did not need many children to benefit from the protective effect of breastfeeding; and if they overdid it (i.e., had many births) the protective effect became damaging. On the other hand, women in the south breastfed for very little, so they needed multiple cumulative births/breastfeeding spells to experience the protective effect of breastfeeding.

Like previous studies, we found that the more children of a woman died, the higher her hazard of death. This effect could be explained either by genetic predispositions running in the family/genes or by exposure to common disasters such as famine or epidemics. Also consistent with previous studies (Alter, Dribe & van Poppel , 2007), we found that widowhood status increased the risk of dying, effect that could be explained by the lack of financial, social and emotional support experienced by widows. The higher risk of dying among different religious groups might be explained through differences in fertility practices (e.g., breastfeeding practices), as well as through other cultural, political and geographic differences. Jewish appear to have a much lower hazard of dying compared to other religious groups, but we cannot place much weight on this finding due to an extremely small sample of this religious group. Finally in our sample, poverty affects longevity, as it affects many social phenomena in most societies. Those in the poor categories of laborers and mixed and unknown occupations, characterized by lack of wealth, had much higher hazard of dying compared to their wealthier counterparts.

Table 1. Descriptive Statistics (part 1)

Variables	Our Analysis Sample: Women who Survived until at least Age 50					All Women				
	Obs.	Min	Mean	Max	Std. Dev.	Obs.	Min	Mean	Max	Std. Dev.
Age at last birth	3010	17.6	38.187	54.57	5.635	4077	13.96	37.018	54.570	6.159
Age at first birth	3010	15.37	26.309	51.36	5.085	4077	13.96	26.097	51.360	4.954
Children ever born	3015	1	5.855	19	3.130	4083	1	5.540	19	3.103
Children ever died	3015	0	2.180	15	2.032	4083	0	1.979	15.0	1.971

Note: For time varying covariate, we chose descriptive statistics for the value at the time of death

Table 1. Descriptive Statistics (part 2)

Variables	Women who lived to be at least 50	All Women
	Percent	Percent
Marital Status		
Married	34.10	47.29
Widow	65.90	52.71
Religion- Region		
Southern Catholics	52.24	52.76
Southern Jewish	0.14	0.56
Southern Protestants	17.84	17.59
Northern Protestants	29.45	29.1
Region		
North	29.45	29.1
South	70.55	70.9
Occupation		
Artisans	24.75	25.45
Civil servants	1.83	1.77
Farmer	33.83	33.12
Mixed & Unknown	13.24	14.1
Nobles	0.07	0.19
Laborers	26.28	26.47

Table 2: Variables included in the analysis

Variable	Description
Dependent variable	
Longevity	The duration in years between age 50 and death.
Main Independent variable	
Age at Last Birth	A dummy variable measuring the age of the women at the last birth in years (After 38=1)
Control variables	
Number of children ever born -Centered (*Parity*)	A continuous variable counting the number children ever born
Total number of dead children (*DeadKids*)	A continuous variable counting the total number of dead children, as a time varying covariate.
Age at first birth- Centered (*Age1stBirth*)	A continuous variable measuring the age of the women at the first birth in years (centered)
Marital status (*Widow*)	A dummy variable accounting for widowhood versus married status (time varying covariate)
Religion (*Catholic, Protestant, Jewish*)	A series of dummy variables
Place of residence (*North*)	A dummy variable accounting for South or North Germany.
Period	A dummy variable taking the value of 0=Year of birth < 1850, 1=year of birth >1850.
Age at last birth Parity*	Interaction as the product of *Age at last birth & Parity*
*Religion*North*	Interaction as the product of *Religion & North*
*Age at last birth *Period*	Interaction as the product of *Age at last birth & Period*

Table 3: Mean Age at Last Birth By Religion and Period

Period	Catholics (Age at Last Birth-Mean)	Protestants (Age at Last Birth-Mean)
Period 1600-1699	37.63	37.17
Period 1700-1799	37.56	37.41
Period 1800-1849	37.62	37.38
Period 1850-1874	36.93	36.28
Period 1875-1899	34.71	32.97
Period 1900-1920	31.15	34.36

Table 4: Gompertz Frailty Regression Models of Longevity after 50 Years of Age

Covariates	Model (1) Shared Frailty with NO interaction	Model (2) Shared Frailty with NO interaction	Model (3) Shared Frailty with 1 interactions	Model (4) Shared Frailty with 2 interactions	Model (5) Unshared Frailty with 1 interactions
	Haz. Ratios	Haz. Ratios	Haz. Ratios	Haz. Ratios	Haz. Ratios
Age at last birth-Dummy (Reference: Before 38 years)					
Age at last birth after 38 years	1.025	1.176**	1.195**	1.187**	1.204**
Age at first birth (Centered)		0.992	0.991	0.990	0.989*
Children ever born (Centered)		0.958**	0.958**	0.965*	0.963**
Children ever died (Time-varying)		1.046**	1.050**	1.050**	1.044**
Marital Status (Reference: Married)					
Widows		1.188***	1.168**	1.169**	1.177***
Religion (Reference: Southern Protestants)					
Southern Jewish		0.346**	0.300**	0.301**	0.450**
Southern Protestants		1.257**	1.196**	1.197**	1.132**
Northern Protestants		0.585***	0.565***	0.565***	0.649***
Occupation (Reference: Farmers)					
Artisans		1.134*	1.114	1.116	1.125**
Civil servants		1.001	1.035	1.037	1.135
Mixed & Unknown		1.542***	1.404***	1.405***	1.340***
Nobles		0.288	0.270	0.272	0.848
Laborers		1.277***	1.205**	1.208**	1.112**
Period (Reference: Before 1850)					
Period after 1850			0.689***	0.687***	0.806**
Age at last birth x Period 1850			0.833	0.837	0.807**
Age at last birth x Children ever born				0.989	
/gamma	0.137	0.134	0.134	0.133	0.089***
/ln_theta	0.763	0.617	0.511	0.512	-2.125**
Theta	2.146***	1.853***	1.667***	1.669***	0.119**

Significance level: * 0.1, **0.05, *** 0.001

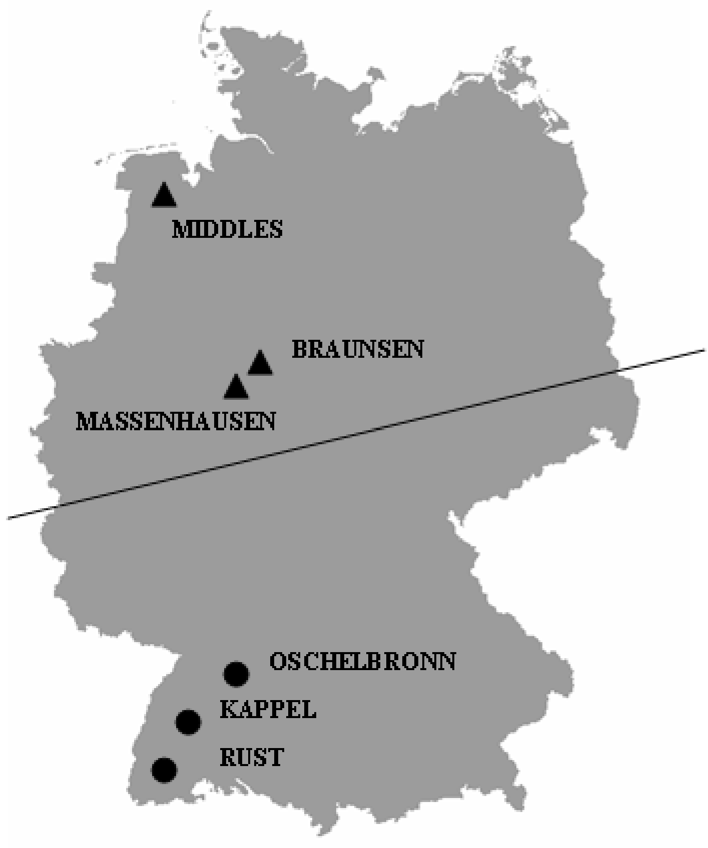

Figure 1. Map of Six German Villages (Knodel, 1988 data). The triangle villages are coded as being in the north while the circle villages are coded as being in the south.

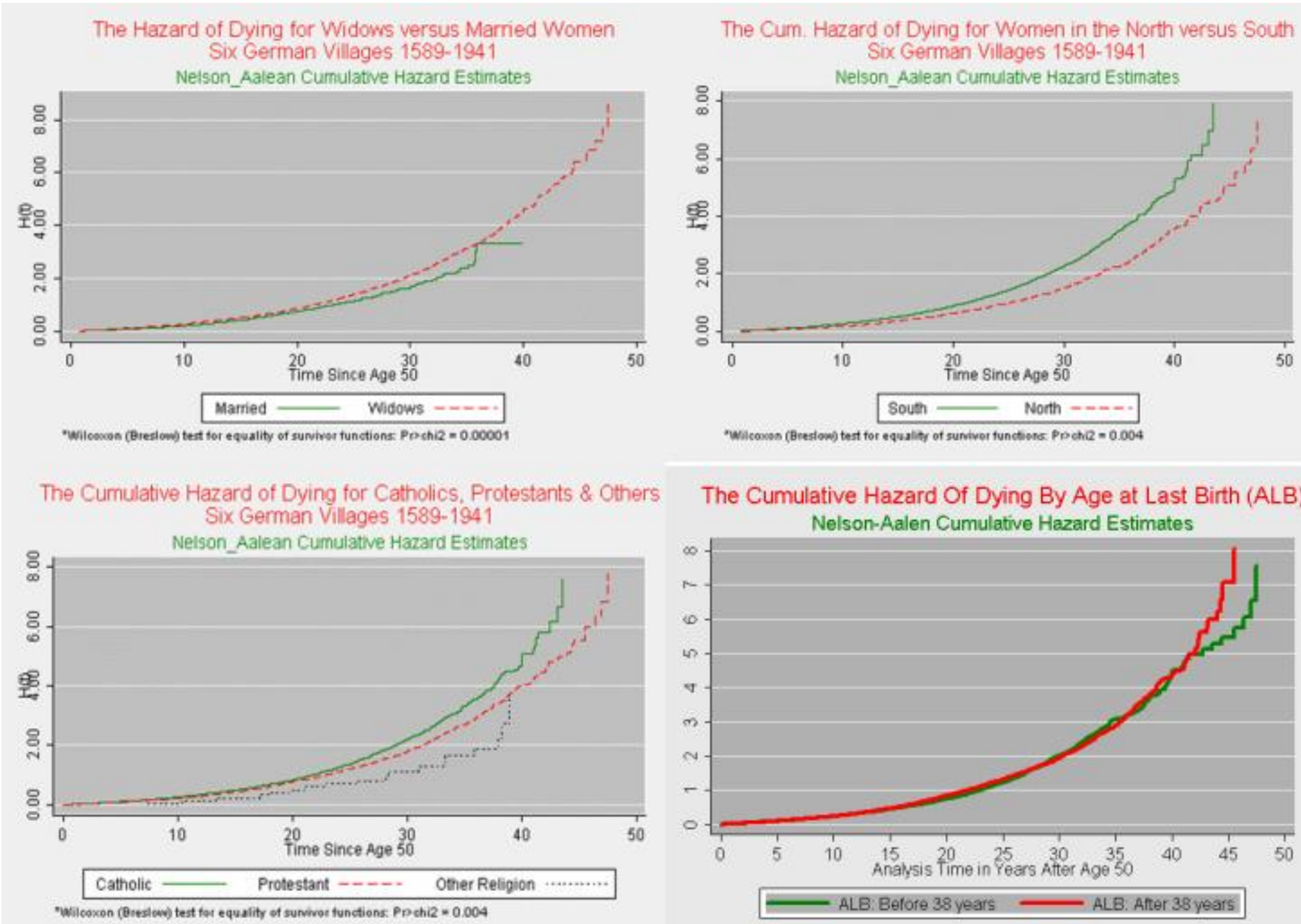

Figure 2. Nelson Aalen Cumulative Hazard Estimates for Various Groups in a Historical Sample of 3024 German Women.

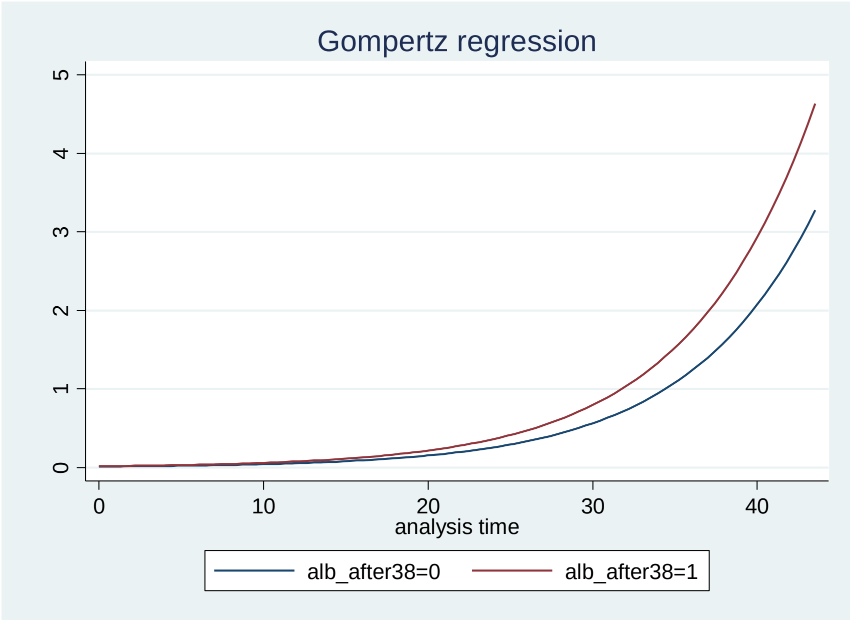

Figure 3a. Individual hazard of dying by “age at last birth” based on a Gompertz model with inverse Gaussian shared frailty in a sample of 6 German Villages (Knodel 1988 data)

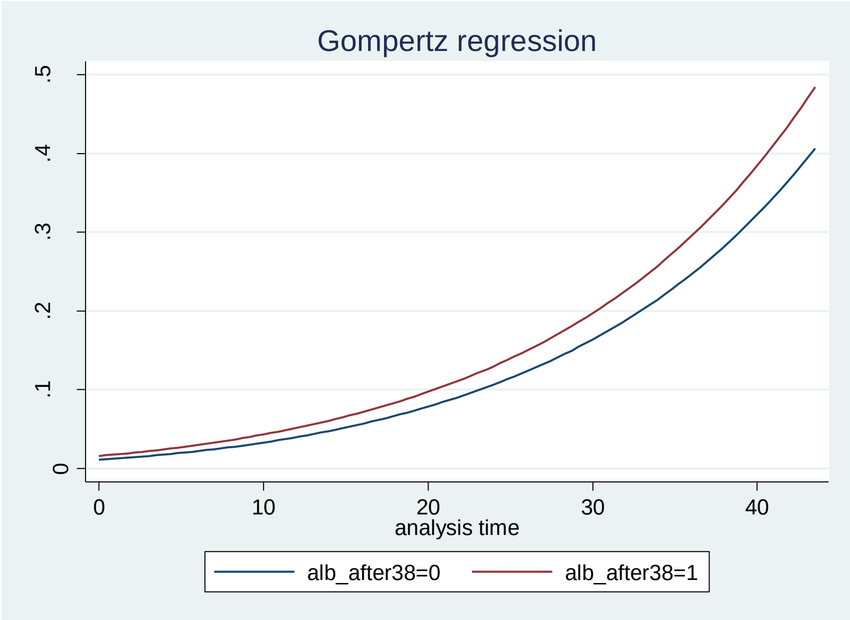

Figure 3b. Population hazard of dying by “age at last birth” based on a Gompertz model with inverse Gaussian shared frailty in a sample of 6 German Villages (Knodel 1988 data)

NOTE FOR REVIEWER: All the graphs, and especially figure 3 will be “beautified” with change of color, addition of titles, change of scale etc. in a later draft of this paper.

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APPENDIX

Table A. Comparison of fit statistics for various versions of Model 3 in Table 4

Models	Covariates	Log Likelihood	AIC
Cox	15	-20869.204	41774.408
Exponential	15	-3437.5124	6911.0248
Weibull	15	-2882.7241	5801.4482
Gompertz-w/ Shared Frailty (PREFERED MODEL)	15	-2648.7916	5333.5832
Gompertz-w/ Unshared Frailty	15	-2724.4954	5484.9908
Log-normal	15	-3602.2243	7240.4486