

Is young adults' excess mortality a universal phenomenon?

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November 2012

Abstract

This study aims to test the respective relevance of different theories of adolescence that picture this age as either intrinsically dangerous, or as vulnerable to the socioeconomic context. By studying the evolution of young adults' excess mortality with the help of mortality models, it becomes clear that this phenomenon is strongly dependant on the historical context. The post-WWII period (women) and the 1930 generation (men) benefited from particular socioeconomic conditions that made the mortality hump disappear. Furthermore, by adapting the Potential Gains in Life Expectancy (PGL) method that allows to ignore the overall mortality context, it is possible to estimate the loss of life expectancy due uniquely to the hump. PGL peaked during the early twentieth century, and then decreased, but only to start a dramatic increase in the last years. These results highlight the socioeconomic nature of young adults' excess mortality and the need to consider this issue in today's public health agendas.

1 Introduction

Over the course of the last centuries, the battle of mankind against death has been largely successful. Compared to the mid-nineteenth century, the world record life expectancy has doubled (Oeppen and Vaupel, 2002), climbing to levels that had been long thought to be out of reach. Although the pace of the progress varied over time (Vallin and Meslé, 2010), it almost never ceased ¹, giving to these gains the appearance of a quite regular process.

These improvements were however distributed very unevenly amongst the different ages of life. In Western countries, before WWII, about half of those gains were made within the first 15 years of life, whereas in the second part of the twentieth century progresses concerned mainly the 60+ age group. Meanwhile, young adults have only played a limited role in the

¹Notable exceptions to this trend were the two World Wars, the HIV epidemics, and the stagnation in the (ex-)Soviet Union since the 1980s (McMichael et al., 2004).

improvement of life expectancy ², which may partly explain the marginal scientific interest that this age group received from demographers.

A few studies have attempted a comparison of young adults' mortality levels over time and across countries (Blum, 2009; Heuveline, 2002; Patton et al., 2009). They highlighted an irregular evolution, marked by an overall but inconstant decrease of mortality, but also by a resistance of certain causes of mortality such as suicides, homicides and traffic accidents. One could describe this evolution as a general erosion of all-age mortality that would progressively reveal a form of mortality that is specific to the young adults and more resistant to public health policies. Young adults' mortality would constitute a sort of residual prominence in the mortality landscape, a form of *demographic inselberg*.

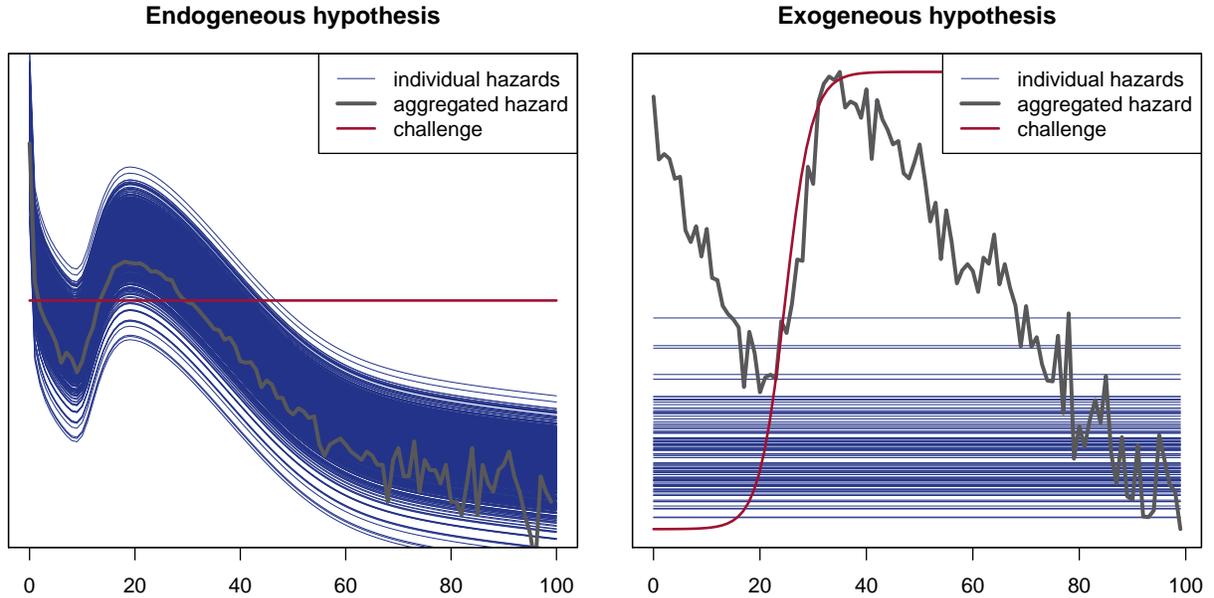
To better put those trends into perspective, one needs to turn to the different theories that have been suggested for the existence of young adults' excess mortality. Two competing hypotheses can be isolated. The first one is rooted in the works of the early scholars of adolescence (Hall, 1904). In this school of thought, adolescence is a universal concept marked, and even defined, by a period of internal disruption and turmoil. Although it has been heavily criticised (Green, 2010), this type of reasoning is still present in the literature. Some psychologists, for instance, argue that young adults (or adolescents) suffer from an intrinsic limited ability to deal with risky situations, due to the biochemical development of their brain (Steinberg, 2005).

On the other hand, one can picture young adults as not intrinsically different from older individuals, but facing a crucial phase of the life course: the socioeconomic and sociocultural challenges associated to their transition to adulthood. Taking their independence from the parental support, completing their education, entering the labour market, entering their first relationships, and becoming parents are important challenges that are specific to this period in life. They all represent potential stressors with which young adults have to cope with unequal resources, and that can trigger the observed excess mortality.

The implication of these two theories in terms of individual mortality hazard are very different (Fig. 1). In the first case, each and every individual experiences an increase in his/her personal hazard during adolescence. The aggregated (observed) risk of death is then the mean of these curves, and results in what demographers usually refer as young adults' *mortality hump*. In the second case, individual hazards may be constant over time, differing only by an unobserved constant measuring their level of vulnerability (socioeconomic frailty). The observed hump, this time, is the effect of selection through unobserved heterogeneity, the most vulnerable individuals dropping out more quickly, leaving a selected group of more resourceful individuals (Vaupel et al., 1979; Vaupel and Yashin, 1985).

²In Switzerland, for instance, only 10% of the 40 years of life expectancy gained between 1876 and 2010 came from the 15-29 age group.

Figure 1: Two alternative explanations for the hump ³



Those two competing theories lead to two opposite conclusions regarding the existence of the hump throughout history. If young adults' excess mortality stems from an intrinsic weakness, a hump should always be observable given that potentially dangerous situations always exist, since it is in young adults' "nature" to engage in them. On the other hand, if the hump comes from the unequal ability to overcome the challenges of the transition to adulthood, then the variations in the force of the latter can reduce or increase the selection process taking place at the individual level. In turn, at the aggregated level, the hump might expand or shrink, at times disappearing.

The aim of this study is to test the validity of these two hypothesis by assessing the existence and size of the hump in a wide variety of contexts. If one can find periods in time when no hump is observable, this will lead to the conclusion that young adults' excess mortality is not a universal and intrinsic phenomenon, but rather a product of the socioeconomic context in which adolescents become adults. By observing the variation in the magnitude of the hump, it should be possible to gain insight into the mechanisms that trigger young adults' excess mortality.

³These two graphs are the results of two microsimulations of each 1 million individuals over 100 periods. At each time t , each individual faces a challenge (red line) with probability of death proportional to his/her individual hazard. These individual hazard vary by a factor (frailty) that is gamma-distributed.

2 Data and Methods

2.1 Data

The Human Mortality Database (HMD) is probably the most comprehensive non-cause-specific mortality database⁴. It covers currently 37 countries over a period that stretches from 1751 (Sweden) to the present day (most recent data range from 2007 to 2010 depending on countries)⁵. For this study, I chose to include as many countries as possible in order to maximize the time and space coverage. The exclusion criteria were twofold. First, only the countries that offered both period and cohort data were considered, causing the elimination of Chile, Israel and Slovenia. Second, a minimum population under exposure was required in order to be able to capture a certain pattern behind the random variations. This requirement was made even more important because of the separate analysis of males and females. This led to the exclusion of Luxembourg (502'000 inhabitants in 2010) and Iceland (318'000 inhabitants in 2011). The final sample consisted in 32 countries covering altogether 2983 years and 2023 cohorts, for each sex (Fig. 2).

The extracted age-specific death rates (ASDR) are split by sex, year and cohort. They are all given by single age and period/cohort in order to maximize the granularity of the data at young ages and facilitate the distinction of potential humps in the curves. In order to avoid important fluctuations due to the small number of survivors and/or absence of data, a cutting point was set at the age of 90. For cohort data, the HMD only provides data up 30 years prior the last period data (i.e. the generations 1977 to 1980 depending on the country).

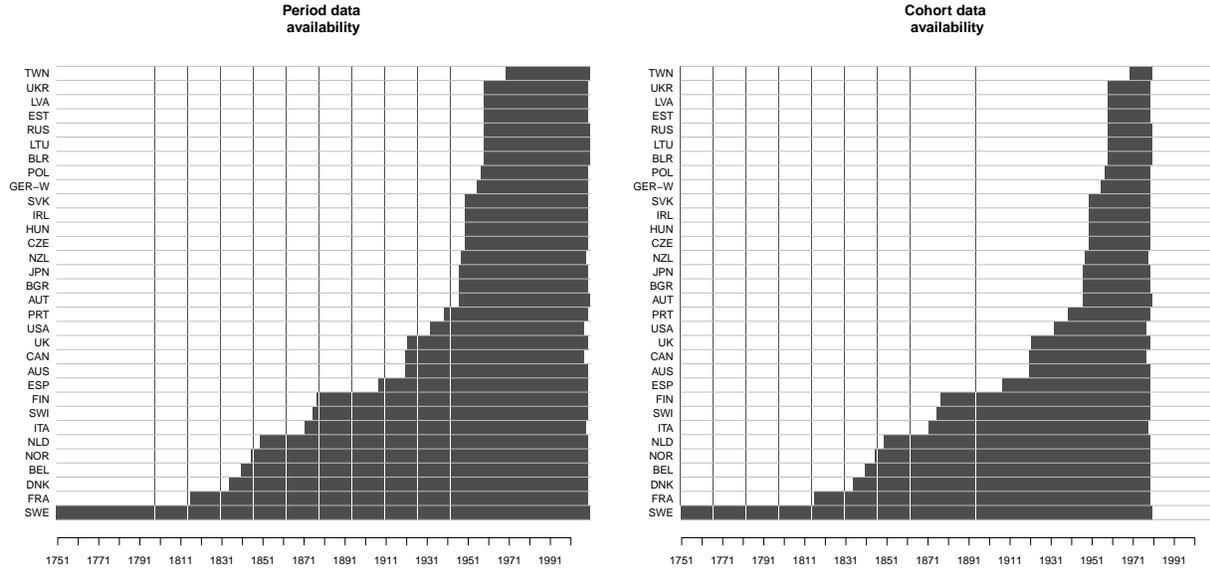
In order to be able to run the subsequent analyses, the truncated cohorts were completed using a Gompertzian trend. Using the formula $\mu(x) = \alpha \cdot e^{\beta x}$ the rate of ageing β was set to 0.1 for all cohorts. The value α was then computed using the mean of the last three known values of $\mu(x)$. The missing values were in turn imputed according to this function. This solution might seem quite radical, but it represents the only possibility to include the youngest cohorts in this study. Moreover, it rests on two solid assumptions. First, the rate of ageing β is a much more stable parameter than α ⁶. Second, the imputed data are not likely to influence the parameters used to model the young adults' mortality hump, given that the rate of ageing is absorbed by the other parameters upon which the analyses do not depend.

⁴The WHO dataset was also considered for its wider geographical coverage, but the 5-year age groups did not leave enough degrees of freedom to properly estimate the models (see method section).

⁵The following description of the dataset corresponds to its state as of the 17th of July 2012, at which date it was downloaded from the project website. Total (civilian) population was selected for France, New-Zealand and the UK. For Germany, only the Western part was included so far for practical reasons, although it would seem desirable to include East Germany in future analyses.

⁶For instance, amongst Swedish females between the age of 40 and 90, the intercept (α) decreased from $8.7e - 5$ to $4.9e - 6$ between 1900 and 2000, i.e. a 17 fold division, whereas the rate of ageing (β) only increased by 20%, from $9.2e - 2$ to $11.4e - 2$.

Figure 2: Human Mortality Database availability



2.2 Methods

2.2.1 Advantages of a model-based approach

Two main flaws of previous studies of young adults' excess mortality are that they rely not only on absolute levels of mortality, but they also use an *a priori* definition of the age bounds of young adulthood. Generally, these studies chose to investigate differences of ASDR for a certain age group, often between 15 and 30 years old. These two choices induce biases in the sense that, first, a drop might not reflect a diminution but instead a postponement of the hump if it is shifting to older or younger ages. Second, the use of absolute measures of mortality impedes from disentangling changes that are specific to the young adults, from evolutions that are common to the whole population. It is therefore essential to find a way to measure the *relative* mortality of young adults, i.e. their excess mortality compared to what one might expect from the general epidemiological context.

These two problems can be solved by using a model-based approach. Tens of models of mortality have been suggested (Wunsch et al., 2002), some as early as the eighteenth century (Moivre, de), but most of the modern formulations are inspired by the Gompertz model (Gompertz, 1825). All include at least two terms that are designed to account for the ex-

ponential increase of $\mu(x)$, and some also contain a term that models the decrease of infant mortality over age (i.e. ontogenescence) (Levitis, 2011), but few take into account the young adults' mortality hump. Chronologically, Thiele proposed the first model that includes the hump (Thiele and Sprague, 1871), but its fit remains limited and it is still mostly ignored by today's demographers and actuaries. Much more common is Heligman and Pollard's model (Heligman and Pollard, 1980) (hereafter HP), which involves eight parameters⁷.

$$HP : q(x) = A^{(x+B)^C} + De^{-E \cdot (\ln(x) - \ln(F))^2} + \frac{GH^x}{1 + GH^x}$$

The main force of the HP model is that each of its parameters has a theoretical interpretation. Concerning the young adults' hump, D measures the height of the hump, E stands for its concentration, and F for the location of its peak. This makes this model superior in terms of interpretation to other models, although the latter were sometimes judged better in their fit (Mode and Busby, 1982; Mode and Jacobson, 1984; Gage and Mode, 1993). Since its formulation, the HP model has been both widely adopted and (mildly) criticised. Although it provides a very good fit for Western male populations in the post-WWII period, it fails to do so for populations where the hump is not prominent, and it has difficulties adapting to some patterns observed more recently. Indeed, one major critic is that, by forcing the concentration of the hump (E) to be equal before and after its peak, the HP model fails to adapt to situations where the hump flattens out after its peak. In order to add more flexibility regarding this aspect, a modified version was suggested by adding an additional parameter that allows for an asymmetric hump (Kostaki, 1992)⁸. This model (hereafter HPk) can be seen as a generalisation of HP (HPk=HP when k=1).

$$HPk : q(x) = \begin{cases} A^{(x+B)^C} + De^{-E \cdot (\ln(x) - \ln(F))^2} + \frac{GH^x}{1 + GH^x} & \forall x \leq F \\ A^{(x+B)^C} + De^{-k \cdot E \cdot (\ln(x) - \ln(F))^2} + \frac{GH^x}{1 + GH^x} & \forall x > F \end{cases}$$

The HPk model offers a flexible enough solution to model almost any force of mortality in which a hump is observable. In order to test whether this hump exists, the HPk model needs to be compared to an alternative model that does not account for the hump. The most famous model of this type (Siler, 1979) includes two terms, one for senescence and one for ontogenescence, plus a constant that accounts for deaths that are independent of age. Using

⁷In order to take into account the observed curvature of the force of mortality at older ages, I will consider here a slightly modified version that was suggested by the authors in their original paper. Moreover, for the purpose of comparability amongst the different models, the response variable was changed from $\frac{q(x)}{p(x)} = \frac{q(x)}{1-q(x)}$ to $q(x)$, a modification that is "almost indistinguishable" according to the authors themselves (Heligman and Pollard, 1980).

⁸In this paper, I chose to slightly rewrite Kostaki's equation, substituting k for E1 and E2 as suggested in the original paper. This aesthetic modification does not change the function at all.

the same structure and adapting it so that the two terms are the same as in HPk, one can build a model that does not account for the hump and is nested with HPk. This new model, HPS, is expressed as follows.

$$HPS : q(x) = A^{(x+B)^C} + D + \frac{GH^x}{1 + GH^x}$$

In the following analyses I will be estimating the two models HPk and HPS on the successive sets of ASDR⁹. The estimation will be done using the standard non-linear least squares (nlS) procedures of the R software (Team, 2012), and representations will use the TraMineR package (Gabadinho et al., 2011). Weights will be defined as $\frac{1}{q_x}$, in order to preserve the normality and homoscedasticity of the residuals¹⁰.

2.2.2 Assessing the existence of the hump

The existence of a hump will be assessed by comparing the improvement of fit brought by the more complex model (HPk) over the simpler model (HPS). This can be measured by the share of the residual sum of squares from HPS that can be explained using HPk. This measure of relative fit ($R2_{rel}$) is computed on the traditional coefficient of determination $R2$ adjusted for the use of weights.

$$R2 = \frac{\sum 1/q_x \cdot (q_x - \bar{q})^2 - \sum 1/q_x \cdot (q_x - \hat{q}_x)^2}{\sum 1/q_x \cdot (q_x - \bar{q})^2}$$

$$R2_{rel} = \frac{R2^{HPk} - R2^{HPS}}{1 - R2^{HPS}}$$

For instance, a $R2_{rel}$ of 0.6 means that 60% of the residual variance from the HPS model can be further explained by the HPk model (i.e. by adding a hump). The significance of this improvement can be assessed by the F-test (Chow, 1960): $F = \frac{(S_{HPS}^2 - S_{HPk}^2)/r}{S_{HPk}^2/(n-p)}$. If the improvement of fit allowed by HPk over HPS is significant, I will then consider that the hump

⁹The ASDR are first transformed into probabilities of death by the classic relation $q_x = \frac{2m_x}{2+m_x}$.

¹⁰In their original paper (Heligman and Pollard, 1980), the authors advise to use simultaneously relative errors and weights, which is in fact equivalent to use cubic weights on absolute errors.

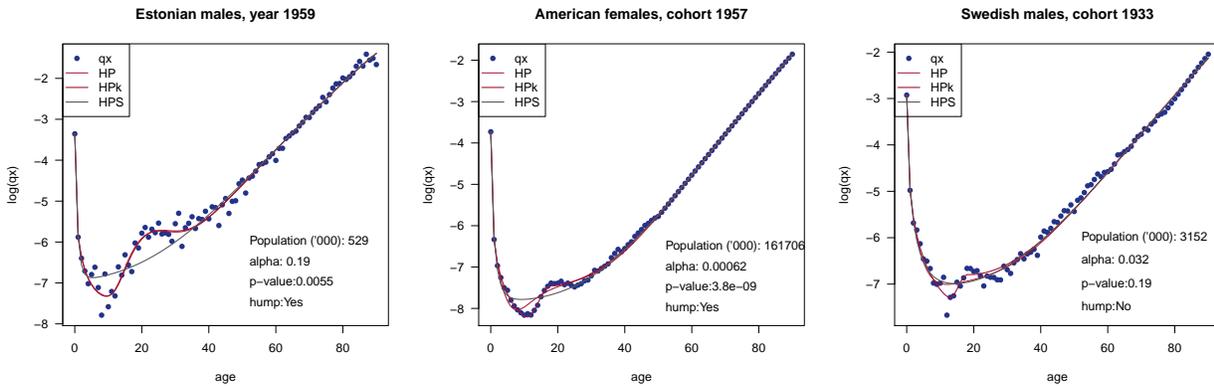
$$S^2 = \sum_{x=0}^{\omega} \frac{1}{q_x} \cdot \left(\frac{\hat{q}_x}{q_x} - 1\right)^2 = \sum_{x=0}^{\omega} \frac{1}{q_x} \cdot \left(\frac{1}{q_x} \cdot (\hat{q}_x - q_x)\right)^2 = \sum_{x=0}^{\omega} \frac{1}{q_x^3} \cdot (\hat{q}_x - q_x)^2$$

After careful examination of the residuals it was obvious that simple weights ($\frac{1}{q_x}$) produce residuals that are both normal and homoscedastic, which is not the case using the procedure suggested by Heligman and Pollard (Gage and Mode, 1993).

exists (Fig. 3).

Fixing the level of significance is not straightforward. Although it is customary to use a fixed level (e.g. 0.05), it is clear that the p-value depends on the size of the population. Indeed, the smaller the population under exposure, the larger the random variation. Since random variation cannot be explained by any model, it becomes harder for the more complex model (HPk) to improve the explained sum of squares, making it harder to reject the null hypothesis of the inexistence of the hump. The level of significance should therefore be set higher when populations are smaller. After a series of trials, the solution of fixing $\alpha = \frac{10^5}{\sum pop}$ was chosen. It results that for a total population of 10 million (per sex), $\alpha = 0.01$, for 1 million it increases to $\alpha = 0.1$, for 100 million it decreases to $\alpha = 0.001$. For cohorts, the population was replaced by the product of the births and T_0 (i.e. the sum of the person-years lived by the people born in that cohort ¹¹).

Figure 3: Examples of fit



2.2.3 Measuring the hump

Assessing the existence of a hump is a good first step, but estimating its size can help carrying the reflection further. As noted previously, when studying young adults' excess mortality, one should avoid *a priori* definitions of the population that is covered by young adulthood. Moreover, one should aim at studying the part of mortality that is not related to the overall level in the general population, i.e. the real *excess* mortality. This means that two successive challenges need to be addressed: to find the boundaries of the hump, and to propose an

¹¹In the actual data, the observed populations ranges from 529'000 to 152 million, and the cohort person-years from 597'200 to 161.7 million. This means that α ranges altogether from 0.19 to 0.0006.

accurate measure of its size.

The question of the limits of young adulthood has received multiple theoretical answers, from both psychologists and sociologists (Green, 2010). Our point here is to temporarily set aside those theories and see what can be said from a demographer's perspective. One main process that links the risk of death and age is usually recognised: senescence, which is defined as "a persistent decline in the somatic function of an organism with increasing chronological age, leading to decreased survival probability and/or fecundity" (Williams and Day, 2003)¹². This phenomenon is empirically measured by the exponential increase in the force of mortality with age, which is captured for instance by the third term (parameters G and H) of the HP model. What is interesting here is the deviation of the force of mortality from this exponential pattern, which forms the hump. Young adults' excess mortality is then defined as the level of mortality that is not explained by senescence.

Building from this definition, one can easily identify the base of the hump, which corresponds to the bottom of the curve and can be defined as the local minimum of the HPk function that is situated before the summit, i.e. $HPk(x_{start}) = \min HPk(x)(x_{start} < F)$. This age indicates when mortality starts to deviate from its expected trajectory if it was only driven by the process of senescence.

The end of the hump can be defined as the age at which the force of mortality does not exceed any more what can be expected if it was only driven by senescence. Statistically, it corresponds to the point where the HPk and the HPS functions meet, i.e. $|HPk(x_{end}) - HPS(x_{end})| = 0(x_{end} > F)$. Unfortunately, this definition is often too idealistic in the case where HPk and HPS only converge asymptotically. There are indeed a non negligible number of cases where the two curves never cross, or only converge at unrealistic values of x, despite being very close over a long interval. A solution to this problem is to set the end of the hump at the first value of x (after the peak of the hump) for which HPk does not better predict the data than HPS. In other words, the hump is considered over when it becomes impossible to distinguish which of the two models is closer to the observed q_x . The first measure is theoretically ideal but practically too versatile, whereas the second one is less "pure" in its conception but more stable in practice. The two measures are often similar, but they can differ sometimes in important proportions, especially when applied to small populations in which random variations are important. Experience showed that taking the mean between those two values leads to the most meaningful results¹³.

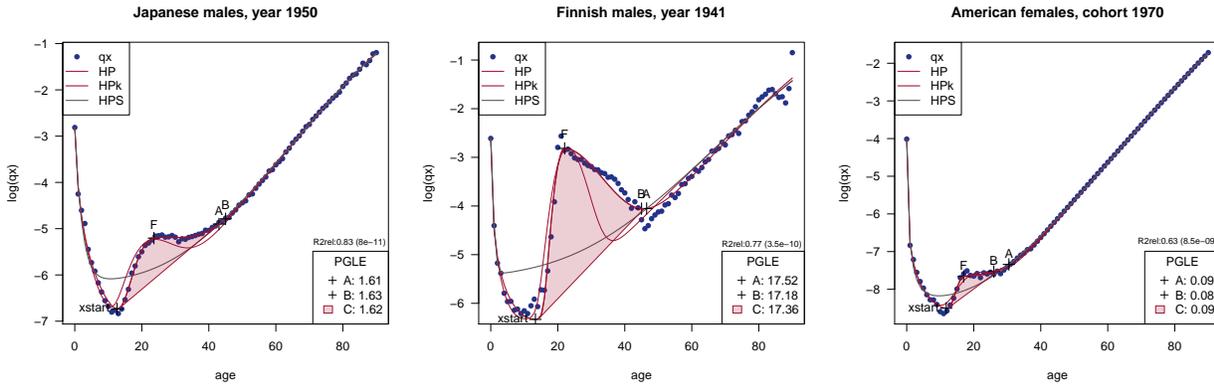
¹²More recently, the term ontogenescence was coined to name the "population-level phenomenon in which the death rate of each cohort tends to decrease with increasing age between conception and maturity" (Levitis, 2011, 801). This, however, as the author suggests, is probably a selection effect and therefore should not be understood at the individual level. The young adults' hump, in the exogenous hypothesis, can be seen as a second phase of ontogenescence.

¹³In the subsequent graphs, the first definition of x_{end} is denoted "A", the second "B" and their average

The second challenge consists in finding an accurate measure of the hump. The parameter D that measures the height of the hump would only improve the classical method (consisting in observing the ASDR at a certain age) to the extent that it measures the height at the peak of the hump. However, it still depends on the overall epidemiological context applying to the general population. A better way to think about it is to focus on the total area that is contained between the curve with the hump and what one would expect from a curve that showed no hump. It is possible to draw a hypothetical curve ($q_{hyp}(x)$) that follows exactly the HPk model ($q_{HPk}(x)$), except over the interval $[x_{start}; x_{end}]$ ¹⁴, during which it increases exponentially, i.e. at the pace of senescence. By computing the life expectancy based on one hand on the HPk model and on the other hand on the hypothetical force of mortality, one can get an idea of the potential gain of life expectancy (PGLLE) if the hump did not exist, i.e. $e_{loss}^0 = e_{hyp}^0 - e_{HPk}^0$. This value does not depend on the overall level of mortality, but only on the total observed amount of deviation compared to a situation without a hump.

Examples of applications (Fig. 4) show that the information on the relative improvement of the fit allowed by HPk is well enhanced by the measure of the size of the hump. Indeed, cases of huge humps, such as the one observed during WWII amongst Finnish males, which costed over 18 years of life expectancy, can be associated with smaller $R2_{rel}$ than smaller humps such as observed amongst Japanese males in 1950 (less than 2 years lost). This is due partly to the amount of random variation in the data.

Figure 4: Limits and size of the hump



”C”. If, for A, the convergence happens after 60 years, the solution is excluded and considered as a case of non-convergence.

¹⁴More precisely, the interval considered starts at the point where the straight line that passes at x_{end} is tangent to HPk. This was designed to avoid crossovers at the bottom of the curve. In practice, this tangent point is very close to x_{start} .

3 Results

3.1 Existence of the hump

The different measures that were presented above were applied to all the 2983 periods and 2023 cohorts of the database ¹⁵. The results regarding the existence or absence of a hump are clear and speak in favour of the exogenous hypothesis. Indeed, although cases with a significant hump represent the majority of observations, there are periods and cohorts in which no hump is observed (Table 1).

	F-period	F-cohort	M-period	M-cohort
no hump	810	488	225	162
hump	2166	1535	2735	1861
% hump	73	76	92	92

Table 1: Proportion of cases with a hump

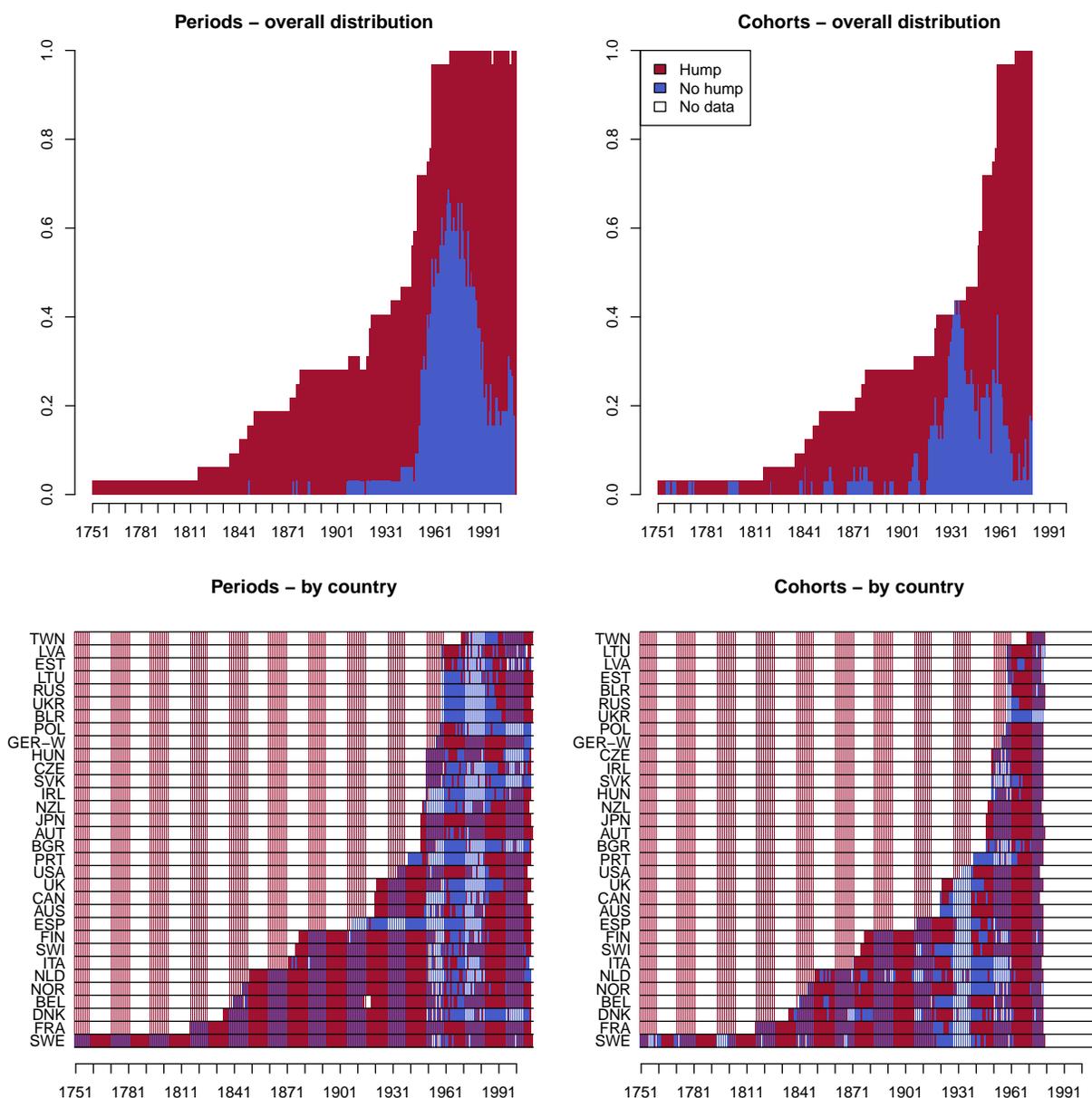
For women, about one quarter of all cases show no hump, against about 10% for men. All countries but Japan experienced at one time or another a case where the hump was non-significant. These figures indicate that the absence of hump in the force of mortality is more than a mere exception; it is a reality that existed in specific times and places in history. This shows without ambiguity that young adults' excess mortality is not a universal phenomenon. Moreover, these moments in time when the hump disappeared are not randomly distributed, they follow a clear pattern that highlights the importance of specific socioeconomic contexts.

Starting with women (Fig. 5), one can identify a long period of time when the hump did not exist in the majority of the countries. This period starts right after WWII, reaches a peak in the late 1960s, and progressively vanishes until the early 1990s. This corresponds to the moment when the 1920s-1960s generations entered adulthood, suggesting that the disappearance of the hump observed in the period data is strongly linked with the processes that took place within the cohorts.

Although at this stage of the analysis interpretation remains to a certain extent speculative, it is indeed possible to use the context of both the epidemiologic transition and the socioeconomic conditions to shed some light on this evolution. First, it is reasonable to assume that the hump before WWII was essentially due to the persistence of maternal

¹⁵Small discrepancies between the number of cases available in the HMD and the results are due to two reasons. First, during WWI Belgium did not record deaths counts, making it impossible to fit the models. Second, in a few cases one or several models did not reach convergence. The total loss of cases amounts to 7 for females and 23 for males, all in the period data.

Figure 5: Existence of a hump: females



mortality. Indeed, after an improvement due to the introduction of antisepsis and asepsis in the late nineteenth century, maternal mortality remained at a plateau during the first four decades of the twentieth century (Loudon, 1988). The decrease in the age at marriage probably played a role in this stagnation by increasing the share of births at an early age, which is a

factor of risk (Bardet and Dupâquier, 1999, 164). However, maternal mortality ratios (MMR) plunged internationally during the 1930s, for reasons that include improvements in medical techniques (first sulphonamides, then transfusions and penicillin), medical education, and general health of the population (especially in the quality of nutrition) (Loudon, 1988). The disappearance of maternal mortality offers then a plausible explanation for the vanishing of young women's hump.

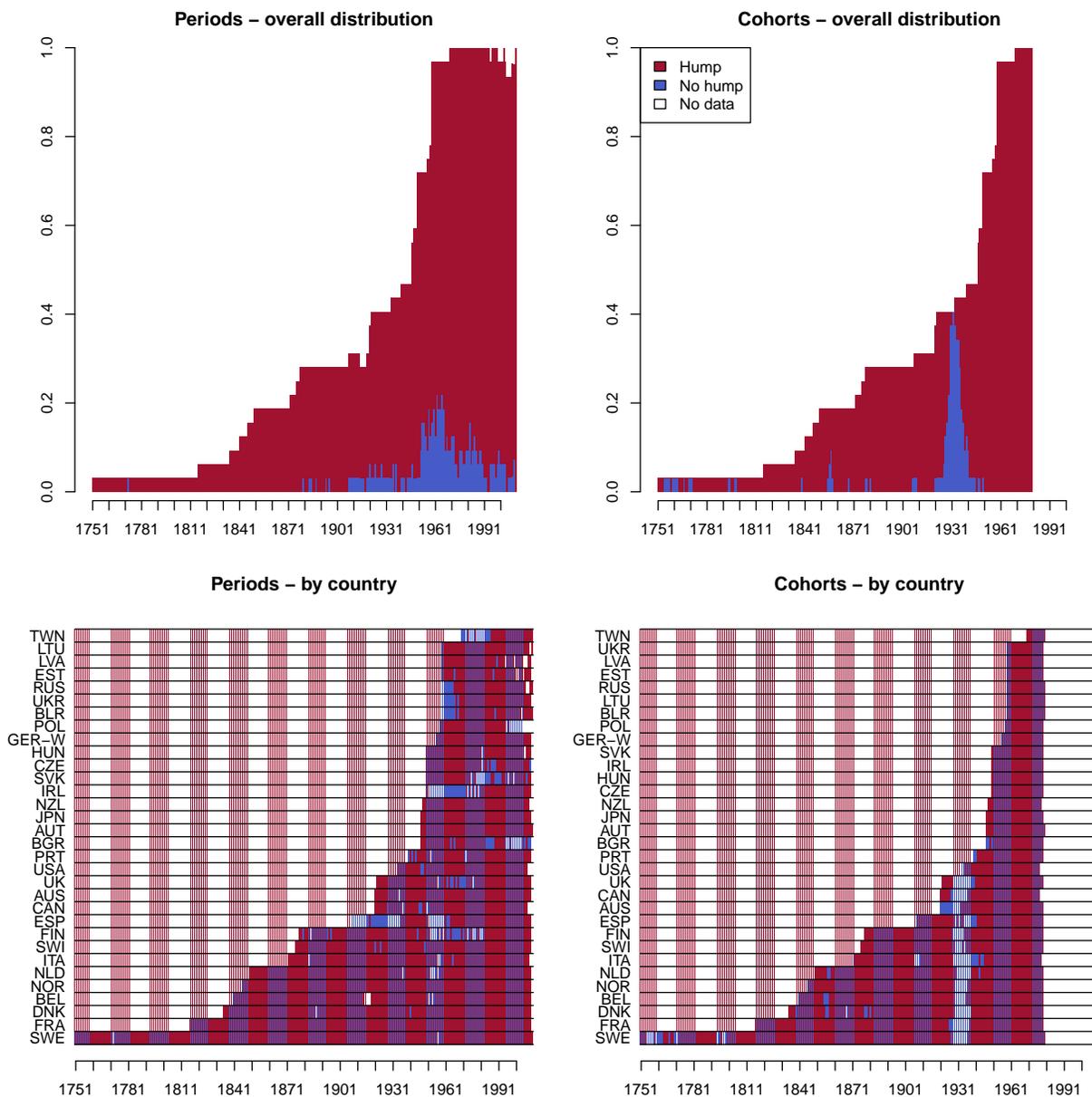
Second, the socioeconomic context of the post-WWII decades was a very special one for women in terms of their participation to the labour market and the division of labour into private and public spheres. Although there are persistent debates on when the male breadwinner model first appeared, one can safely assert that it reached its apogee in the central decades of the twentieth century (Janssens, 1997; Lewis, 2001; Pfau-Effinger, 2004). The conceptions that had been diffused by the elites of the bourgeoisie since the nineteenth century were applied massively when the general improvement in the standards of living allowed households to rest entirely on the single income of men. This peculiar state of extreme gendered segregation evolved progressively over the last decades of the last century. The gendered division between paid and household labour, the gendered labour market that confined women to non-physical jobs, combined with a construction of femininity that emphasised self-control and avoidance of potentially "dangerous" activities (Duby et al., 1991; Vallin, 1988) could all provide parts of the explanation as to why the hump disappeared amongst women, and then reappeared in the 1980s.

As for men (Fig. 6), the pattern is similar but weaker. From the period point of view, the post-WWII era also witnessed a partial disappearance of the hump, which did not concern more than 20% of the observed countries, as opposed to 60%-70% for women. Clearly, this confirms a gendered socioeconomic context particular to the post-war decades. However, one should not conclude from this observation that men are always subject to the young adulthood's hump.

Indeed, from the cohort perspective, one can observe a very striking phenomenon. In all the countries, the generations of men born between approximately 1925 and 1935 experienced no hump. For the 1932 birth cohort, no country that offers data shows any significant hump. This must be interpreted in relation to the context in which they entered adulthood. These men were between the age of 10 and 20 at the end of WWII. They were too young to be soldiers, but could provide the labour force that was needed for the reconstruction of the economies that had been devastated during the war. Compared to the scarcity they had witnessed during their childhood, the world they were entering was one of foreseeable abundance.

The same argument was already used to explain the baby-boom, an equally exceptional phenomenon for which this very same generation is responsible by its exceptionally high fertility. Considering the effect of cohort sizes on the relative economic position of young

Figure 6: Existence of a hump: males



males, Easterlin showed that at the end of WWII, young workers enjoyed a time of increasing incomes and very low unemployment that followed almost perfectly the evolution of their fertility (Easterlin, 1978). These *Children of the Great Expansion* were part of a blessed generation; which confirms how the conditions in which generations enter adulthood influence

their entire subsequent course (Elder Jr, 1974).

Overall, the periods in which the hump disappeared for men and/or women are clearly clustered around a moment in history characterised by minimal insecurity (maximal predictability) during the 1945-1973 economic expansion, the development of lifelong careers, and the pinnacle of the so-called traditional family. In those conditions, entering adulthood was a foreseeable process during which, after finishing a relatively short education, the large majority of individuals could expect to quickly find a stable job with good advancement perspectives, as well as to get married and have children within a few years. By contrast, the last decades have witnessed an increase of uncertainty in the (early) life course, which was concentrated mainly on the young adults (Blossfeld, 2008). Young adults' unemployment, fixed-term contracts, late leaving home, and postponed stable relationships are traits of the current socioeconomic climate. Together, they have increased the pressure on young adults and are the most probable explanation for the reappearance of young adults' excess mortality.

3.2 Dimensions of the hump

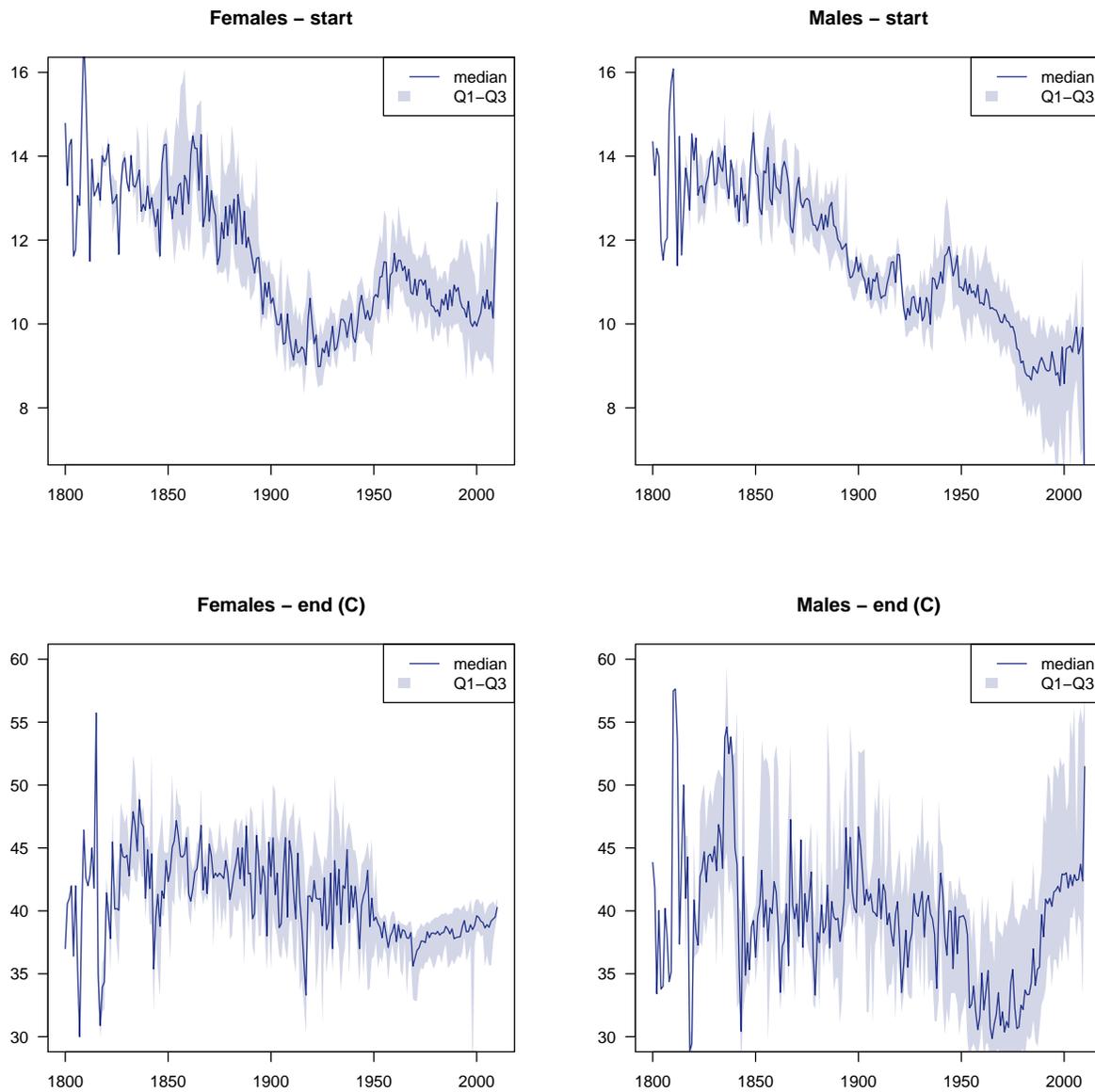
Exploring first the limits of the hump, the results are quite astonishing (Fig. 7). In general, the hump covers an age interval much larger than what is usually admitted. Over time, it ranged from 20 years in the early nineteenth century, to almost 35 years in the first half of the twentieth century. Between one third and one half of the total life span is therefore affected by a level of mortality that exceeds the pace of senescence.

Second, regarding the base of the hump, one can observe a similar decreasing trend for men and women. This means that, over time, children have entered adulthood at a gradually earlier age. This result is surprising considering the progressive generalisation of public mandatory education and the ban of child labour since the nineteenth century. More precisely, it is possible that the temporary rise in the base of the hump between 1900 and 1950 is a result of those policies. However, since the 1950s the end of childhood has advanced until reaching an average of 10 years old ¹⁶. A more biological explanation would be the decreasing age at menarche due to the improvement in child health (Gluckman and Hanson, 2006).

Third, the hump seems to disappear at a much older age than expected. Although this measure is much more versatile than the first one for the reasons raised earlier, the median of the observation shows a stable pattern around age 40. The rise of the median for men after 1990 could be explained by the influence of the post-communist countries, where the mortality pattern went under rapid changes. This needs however more thorough investigation.

¹⁶The last observations, after 2000-2004, are less reliable due to the shrinking of the dataset.

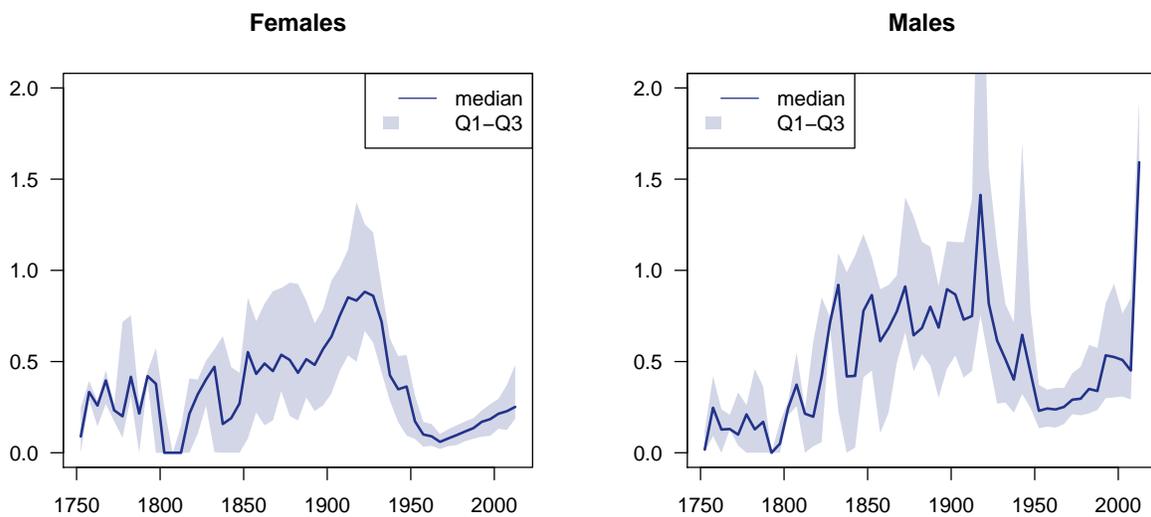
Figure 7: Limits of the hump (for all 32 countries)



To conclude the measures of the hump, the potential gains in life expectancy (PGLE) for the hump gives us an idea of how many years longer people would live on average if it was not for the hump (Fig. 8). Results show a general bell-shaped curve for men and women. During the nineteenth century, life expectancy lost to young adults' excess mortality increased from

less than half a year to a maximum of one year. During the first part of the past century, this loss was progressively compressed, but it picked up in the last decades, almost reaching again the figures that were known one century ago. In the last years, the progression has reached an impressive pace, and in some countries the loss exceeds now 2 years of life expectancy for men and 1 for women. The situation is especially critical in Eastern Europe (Russia, Hungary, Ukraine, Baltic countries), but countries like France, Finland or Portugal (men, above 1), as well as Switzerland, Ireland and Norway (women, above 0.5) also show high figures.

Figure 8: Potential Gains in Life Expectancy
5 year intervals



For comparison purposes, PGLE¹⁷ for neoplasms were estimated for the USA in the period 1997-2008¹⁸. The results show that women would gain about 5 years, and men 4 years of life expectancy by the removal of neoplasms-related deaths. Meanwhile, the PGLE for the hump reaches about 0.25 years for women and almost one year for men. Compared to a cause of mortality that is responsible for about one quarter of all deaths in the USA, only second to the cardiovascular diseases (WHO, 2011), these figures show that the young

¹⁷”The PGLE, by the elimination of deaths from a particular cause, is the added years of life expectancy for the population if the deaths from that cause were removed or eliminated as a competing risk of death” (Lai and Hardy, 1999, 895). It resembles our measure in the sense that it compares the actual life expectancy to a hypothetical state where a certain type of mortality is ignored.

¹⁸Own calculation based on the data of the World Health Organization.

adults' hump is not negligible, especially for men.

4 Conclusion

The motives of this study were first to question the universality of young adults' hump, and second to propose new methods to measure its dimensions. These goals have been both achieved and strong conclusions can be drawn regarding the nature and evolution of young adults' excess mortality.

First of all, this study established young adults' excess mortality as a social, and not (only) as a biologically determined phenomenon. Theories of adolescence sometimes depict the transition to adulthood as a time of internal turmoil during which intrinsic weaknesses limit the young adults' faculty to adopt safe behaviours. If this was true, one should always observe a mortality hump in all contexts, yet the facts do not confirm this theory. In certain contexts where uncertainty is at its lowest and the challenges of the transition to adulthood are at their weakest, the hump disappears. In other words, young adults' excess mortality is a social fact (*fait social*) as defined by Durkheim (1895).

Second, this study established the importance of the hump in terms of public health. By the age span that it covers, the hump concerns a much larger share of the population than previously thought, from the early teens to about 40 years of age. Specifically, analysing young adults' excess mortality cannot be limited any more to classical age definitions such as the 15-30 years old. In terms of its burden on life expectancy, the hump has been maximal in the first years of the last century, for both men and women, before reaching a minimum in the years that followed WWII. It has however regained in importance in the last decades, reaching levels that should cause worry in the minds of the governments and suggest that young adults' mortality should not be left aside in today's public health agendas.

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