

How We Fall Apart: Similarities of Human Aging in 10 European Countries

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Abstract. We analyze human aging, understood as health deficit accumulation, for a panel of European individuals. For that purpose, we use four waves of the Survey of Health, Aging and Retirement in Europe (SHARE dataset) and construct a health deficit index. Results from log-linear regressions suggest that, on average, elderly European men and women develop about 2.5 percent more health deficits from one birthday to the next. In non-linear regression (akin to the Gompertz-Makeham model), however, we find much greater rates of aging and large differences between men and women as well as between countries. Interestingly, these differences follow a particular regularity (akin to the compensation effect of mortality). They suggest an age at which average health deficits converge for men and women and across countries. This age, which may be associated with human life span, is estimated as 102 ± 2.6 years.

Keywords: health; aging; health deficit index; Europe; gender differences; compensation law, human life span.

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1. INTRODUCTION

Aging is defined as the intrinsic, cumulative, progressive, and deleterious loss of function (Arking, 2006; Masoro, 2006). In this paper we investigate human aging, thus defined, for a panel of European individuals. For that purpose, we use four waves of the Survey of Health, Aging and Retirement in Europe (SHARE dataset) and construct a health deficit index for 50 to 90 years old men and women in 10 countries. In contrast to the related literature using the SHARE data, we apply a particular theory-led modeling, which allows us to detect regularities of human aging that remained unnoticed in the previous literature. Specifically we show the existence of a “compensation effect of deficit accumulation” (CEDA), i.e. a linear negative relationship between initial health deficits and the rate of health deficit accumulation. According to CEDA, men start out healthier than women but then develop additional health deficits at a higher rate. Similarly, the rate of health deficit accumulation is higher in countries in which individuals are, on average, initially healthier. CEDA implies convergence of *group-specific* aging processes such that there exists a *species-specific* age at which health deficits converge for men and women as well as across countries. The point estimate for this invariant of human aging, which could be conceptualized as human life span, is about 102 years.

Our analysis is inspired by two strong empirical regularities observed for human mortality: the Gompertz-Makeham law and the compensation effect of mortality. Gompertz (1825) proposed that age x and the rate of mortality $\mu(x)$ are log-linearly related. Makeham (1960) added a constant for age-unrelated mortality, providing the Gompertz-Makeham law of mortality, $\mu(x) = A + R \exp(\alpha \cdot x)$. The parameters of this non-linear relationship have been estimated with great precision for different human populations indexed by i and differentiated, for example, by gender and country of residence (see e.g. Arking, 2006; Olshansky and Carnes, 1997). The second regularity describes a strong negative relationship between the Gompertz-parameters R_i and α_i , which holds across populations, such that $\ln(R) = \ln(M) - B\alpha$. This “compensation effect of mortality” (Gavrilov and Gavrilova, 1991), also known as Strehler-Mildvan (1960)-correlation, implies that populations with lower initial mortality (characterized by lower R_i) display a larger increase of mortality with age (characterized by higher α_i). It also means that the estimates M and B provide species-specific invariants of human mortality. To see this more clearly, substitute R to obtain the age-related mortality rate $\mu(x) - A = Me^{\alpha(x-B)}$, suggesting that in all populations there exists an age B at which individuals face the same mortality rate

M. The age B has been conceptualized as human life span (Gavrilov and Gavrilova, 1991; Strulik and Vollmer, 2013).

In this paper we show that a similar compensating law holds for human morbidity. This view is inspired by the reliability theory of human aging. Reliability theory explains how complex systems consisting of non-aging elements (e.g. atoms) increasingly lose function over time, such that the failure rate, i.e. the probability of expiry of the system increases with age (Barlow and Proschan, 1975). Human aging is thus conceptualized as a loss of redundancy in organ reserve over time. Gavrilov and Gavrilova (1991) derived the Gompertz law of mortality as well as the compensation effect of mortality from such a microfoundation of aging at the cellular level (see also refinements by Noveltsev, 2006; Finkelstein, 2008). Since reliability theory holds also at the subsystem level (of, e.g., organs) it is easy to see why not only mortality but also the loss of bodily functions (i.e. health deficit accumulation) follows the Gompertz-Makeham law. In particular, CEDA is easily rationalized with reliability theory: initially healthier individuals possess greater organ redundancy such that organ reserve declines at a higher rate leading to a faster speed of health deficit accumulation. The notion of aging as accelerated loss of organ reserve is in line with the mainstream view in medical science. For example, initially, as young adults, the functional capacity of human organs is estimated to be tenfold higher than needed for survival (Fries, 1980).

Our analysis is built on Mitnitski et al. (2002a) who constructed a health deficit index (frailty index) for Canadians and estimated with non-linear regression the parameters of the Gompertz-Makeham structure introduced above.¹ They estimated a yearly rate of health deficits accumulation of 4.3 percent for men and 3.1 percent for women. Men were found to be initially healthier, a fact that can easily be explained by reliability theory: men are on average larger and have thus a larger organ reserve (e.g. more bone mass, more muscle mass) to wear off during aging. Moreover, Mitnitski et al. (2002a) found an intersection of the health deficit trajectories of men and women at age 95, which they associate with human life span estimated from the compensation effect of mortality. While the particular age of intersection is certainly interesting, their study provides, strictly speaking, only weak support of the compensation effect of health deficit accumulation since any two non-parallel trajectories have to intersect somewhere. In this

¹Originally, the methodology was established by Mitnitski, Rockwood, and coauthors as the frailty index. Newer studies use also the term health deficit index (e.g. Mitnitski and Rockwood, 2016), which seems to be a more appropriate term when the investigated population consists to a significant degree of non-frail persons.

paper we estimate the average life-time trajectories of health deficit accumulation for a panel of 10 European countries and show that the compensation effect of health deficit accumulation holds across countries for both men and women. A common intersection of 20 life-time trajectories is, of course, much harder to be dismissed as pure coincidence. In this sense, the European compensation effect of health deficit accumulation provides a first piece of evidence for a species-specific invariant of human aging.

The seminal papers on the health deficit index by Mitnitski et al. (2001, 2002a,b) have instigated a by now very large research program with hundreds of studies applying the methodology. One reason for the success of the health deficit index, computed as the ratio of the number of health deficits to the total number of deficits considered, is that it is easily understood and implemented (see Mitnitski et al., 2006, 2007 for methodological background). The convenience of the health deficit index becomes particularly salient when we compare it with health capital, i.e. the latent variable in the focus of many studies in health economics (following Grossman, 1972). Moreover, as sketched above, the accumulation of health deficits has a micro-foundation in reliability theory, which facilitates the formulation of theory-led hypotheses and the scientific exchange of the disciplines concerned with human aging.

A couple of studies investigated the health deficit index (frailty index) using the SHARE data (Romero-Ortuno and Kenny, 2012; Harttgen et al., 2013, Theou et al., 2013; Romero-Ortuno, 2014).² These studies focused mainly on the association of health deficits with mortality as well as with several socioeconomic indicators and on comparing health deficits of Europeans and citizens of selected developing countries. None of the available studies exploited the panel structure of SHARE for longitudinal analysis. Here we also run fixed- and random effects panel regressions and demonstrate a log-linear relationship between age and health deficits at the individual level. In fact, the fixed effects estimates differ slightly from the results obtained from pooled data and re-adjust the sometimes inconclusive findings regarding the gender gap of health deficit accumulation obtained in previous studies (e.g. Harttgen et al., 2013). According to the log-linear regression results, men (women) develop on average 2.6 (2.3) percent more health deficits from one birthday to the next. Non-linear regression, however, suggests a much higher

²On a more general level, our study is also related to the literature on the compensation effect of mortality, aka the Strehler-Mildvan correlation (Yashin et al., 2001; Zheng et al., 2011; Strulik and Vollmer, 2013; Zheng, 2014) as well as to the general discussion of human life span (Finch and Pike, 1996; Gavrilov and Gavrilova, 1991; Yashin, 1997; Carey, 1997, 2003; Oeppen and Vaubel, 2002; Carnes and Olshansky, 2007; Wilmoth and Robine, 2003).

impact of age on health deficit accumulation. When we take the constant (the Makeham term) into account we estimate a rate of health deficit accumulation of 7.3 percent for men and 5.2 percent for women as well as a highly significant constant (which does not differ between gender in the full sample).

The paper is organized as follows. In Section 2 we describe the dataset and estimate the relationship between the health deficit index (measured as the proportion of deficits that an individual has) and the age of the individuals. Then we proceed with the estimation of the same relationship but with the average values of the index for each age group (defined as all of the individuals within a specific age i.e. 50, 51, etc until 90), for each wave, and for each country. The panel analysis is based on a balanced panel since there is some attrition in the sample (about 9% of the people surveyed on wave 1). In the Appendix we show that our results barely change when we include individuals that passed away through the different waves (considering attrition by death). This robustness analysis is important given that our dependent variable is health-related. We then proceed with the estimation using the binned data of the individuals in the sample within the age-frame under study, by year of age separately for each wave and then for each country. In Section 3 we estimate the compensation effect of deficit accumulation and discuss the convergence of gender specific aging across Europe. Section 4 concludes the paper.

2. EMPIRICAL STRATEGY AND BASIC RESULTS

2.1. Data description. For the empirical analysis we used the Survey of Health, Aging and Retirement in Europe (SHARE dataset release 5.0.0)³ and considered the four waves (1, 2, 4 and 5) that provide health-related information (see Börsch-Supan et al. (2013) and Gruber et al. (2014) for methodological details).⁴ Wave 1 took place in the year 2004, wave 2 in 2006/7, wave 4 in 2011 (in 2012 for Germany) and wave 5 in 2013. We considered individuals aged 50 and above of the 10 countries that participated in all 4 waves: Austria, Belgium, Denmark, France, Germany, Italy, Netherlands, Sweden, Spain and Switzerland.⁵ We only kept individuals until age 90 since a significant share of older people show “super healthy” characteristics, presumably

³DOIs: 10.6103/SHARE.w1.500, 10.6103/SHARE.w2.500, 10.6103/SHARE.w4.500, 10.6103/SHARE.w5.500

⁴We also made use of part of the Easyshare release 2.0.0 to compile the dataset.

⁵Although the main target is to survey adults of age 50 or above (aiming at the creation of a dataset that is representative of the non-institutionalized population of age 50+), younger people can also be found in the data since partners are also interviewed. These were removed since they do not belong to the representative sample.

because of selection effects. While Mitnitski et al. (2002a) considered individuals up to the age of 79, Harttgen et al. (2013) considered the whole age span.

For each individual we constructed a health deficit measure following Mitnitski et al. (2002a) and Harttgen et al. (2013). Since we understand aging as the accumulation of health deficits, based on the available data, we considered 38 symptoms, signs and disease classifications, as summarized in Table 6 in the Appendix. Details on how each variable was constructed can be found in Table 7 in the Appendix.⁶ We then computed the health deficit index as the proportion of deficits that an individual suffers from. When there were missing data for an individual, we computed the deficit index based on the available information about potential deficits (i.e. if for an individual information was not available for x potential health deficit, the observed health deficits were divided by $38 - x$). From the surveyed individuals we kept only those who had a health deficit index with at least 30 items. Due to missing values in the construction of the health deficit index or because of the lack of sufficient deficits to reach the 30 items minimum we lost 2.2% of the potential dataset. Table 8 in the Appendix shows how the observations are distributed in each wave, while Table 9 also in the Appendix shows the number of observations by gender and country of residence for the full sample (left-hand side) and the balanced panel (right-hand side).

2.2. Panel estimates. In this section we estimate the log-linear relationship between age and health deficits with the following equation:

$$\ln D_{igw} = r_g + \alpha_g \cdot age_{igw} + \epsilon_{igw} \quad (1)$$

where i represents the individual, g the gender (we ran separate regressions for males (m) and females (f)), and w the wave; ϵ is the error term. We subsequently add further covariates composed of wave dummies and/or country or country-wave dummies. Note that, in terms of the Gompertz-Makeham methodology, Equation 1 estimates a Gompertz-relationship, without consideration of the Makeham term. Formally, we assume that $A_g = 0$ in the non-linear equation $D_{igw} = A_g + R_g \exp(\alpha_g \cdot age_{igw})$, $R_g = \exp(r_g)$, for gender $g = f, m$.

Results are shown in Table 1 and Table 2. Column (1) shows results for the simple specification (Equation 1). Column (2) further includes wave dummies, column (3) adds country dummies.

⁶Here, we followed Mitnitski et al. (2002a) and coded multilevel deficits using a mapping to the Likert scale in the interval 0-1. We also computed binary deficits using cut-off points, as suggested by Pena et al. (2014), and found that the two indices were not statistically different from each other, across waves and across subgroups.

Column (4) adds country-wave dummies to the specification of column (2) while column (5) provides results for a random-effects specification that also includes wave dummies. Finally, column (6) provides the results of a fixed effects specification. We conducted the Breusch-Pagan Lagrange multiplier (LM) test (Breusch and Pagan, 1980) using age and wave dummies as explanatory variables, and the test suggests that the random effects estimator is more appropriate than the pooled OLS for both males and females. We also perform a Hausman test. For women (but not for men), the tests suggests that there is some evidence of unobserved heterogeneity that would be biasing the random-effects results. Nevertheless, for both men and women the coefficients remain fairly constant. In Table 17 in the Appendix (Section ??) we show that we obtain similar results when the maximum age of individuals in the sample is restricted to 85 (rather than 90).

The results summarized in Tables 1 and 2 show that the health deficit index increases by about 2.5 to 3 percent from one birthday to the next. While this stylized fact is obtained across methods other features are less robust. In particular the pooled data and random effects regressions (1)-(5) suggest that women age faster than men in contrast to the earlier finding of Mitnitski et al. (2002a). The regression considering individual fixed effects, however, reverses this result by estimating a (mildly) higher rate of health deficit accumulation for men. In longitudinal perspective the rate of deficit accumulation is 2.3 percent for women and 2.6 percent for men.

The sign of the wave dummies is also inconclusive across methods. The fixed effect estimates, however, suggest that both men and women got on average healthier in wave 2 and unhealthier in wave 4. This finding could be explained by a generally positive effect of medical technological progress, which is the dominant force in wave 2 but which is offset and reversed in wave 4 by the negative repercussions of the Great Recession on health.

We also observe great differences in health across countries. As shown by the country dummies in (3), the health deficit level of Spaniards and Italians is on average higher than the one of Austrians, while the one of Swedes, Danes, and Swiss (also Dutch for males) is on average lower than the one for Austrians. There seems to be no difference in being Belgian, German or French with respect to being Austrian, in terms of health deficit accumulation.

TABLE 1: WOMEN AGED 90 OR YOUNGER. PANEL RESULTS.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Age | 0.029*** (0.001) | 0.030*** (0.001) | 0.029*** (0.001) | 0.029*** (0.001) | 0.030*** (0.001) | 0.023*** (0.001) |
| Wave 2 | | -0.063*** (0.009) | -0.062*** (0.009) | 0.042 (0.050) | -0.063*** (0.009) | -0.043*** (0.008) |
| Wave 4 | | -0.007 (0.012) | -0.003 (0.012) | 0.148*** (0.049) | -0.007 (0.012) | 0.042*** (0.008) |
| Wave 5 | | -0.063*** (0.014) | -0.057*** (0.014) | 0.034 (0.051) | -0.063*** (0.014) | |
| Germany | | | 0.053 (0.047) | | | |
| Sweden | | | -0.157*** (0.044) | | | |
| Netherlands | | | -0.067 (0.044) | | | |
| Spain | | | 0.342*** (0.043) | | | |
| Italy | | | 0.283*** (0.041) | | | |
| France | | | 0.065 (0.043) | | | |
| Denmark | | | -0.154*** (0.048) | | | |
| Switzerland | | | -0.308*** (0.051) | | | |
| Belgium | | | 0.054 (0.040) | | | |
| Constant | -3.906*** (0.064) | -3.909*** (0.069) | -3.914*** (0.076) | -3.967*** (0.080) | -3.909*** (0.069) | -3.473*** (0.076) |
| R^2 | 0.119 | 0.121 | 0.176 | 0.177 | 0.122 | 0.061 |
| Observations | 17,596 | 17,596 | 17,596 | 17,596 | 17,596 | 17,596 |
| Country | All | All | All | All | All | All |
| Dummy Var./other | - | Wave | Wave + country | Countrywave + wave | Wave (plus RE) | FE + wave |
| Age restr. | 90 | 90 | 90 | 90 | 90 | 90 |
| Individuals | 4,411 | 4,411 | 4,411 | 4,411 | 4,411 | 4,411 |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of the health deficit index is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

A valid concern is whether these results suffer from a sample selection since we only considered people alive throughout the waves. To test whether the results are biased due to not considering the people that died across the waves⁷, we performed the variable addition tests including these extra observations, as suggested by Verbeek and Nijman (1992) and also employed by Contoyannis et al (2004). We estimate the same baseline regressions as in the previous exercise and we added 3 different variables (one at a time). The variables include: “Wave sum” (how many times was a person present in the sample); “Balanced” (whether this person was present in all the waves), and “Next wave” (whether the person is in the next wave or not). Although the extra variable is statistically significant; for most of the cases, we find no evidence that the

⁷The SHARE dataset provides information on whether people left the sample because they passed away.

TABLE 2: MEN AGED 90 OR YOUNGER. PANEL RESULTS.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Age | 0.026*** (0.001) | 0.025*** (0.001) | 0.024*** (0.001) | 0.024*** (0.001) | 0.025*** (0.001) | 0.026*** (0.002) |
| Wave 2 | | -0.036*** (0.013) | -0.033*** (0.013) | -0.013 (0.070) | -0.036*** (0.013) | -0.038*** (0.010) |
| Wave 4 | | 0.066*** (0.016) | 0.073*** (0.016) | 0.119* (0.070) | 0.066*** (0.016) | 0.063*** (0.010) |
| Wave 5 | | 0.004 (0.019) | 0.013 (0.019) | 0.003 (0.072) | 0.004 (0.019) | |
| Germany | | | 0.010 (0.063) | | | |
| Sweden | | | -0.261*** (0.060) | | | |
| Netherlands | | | -0.221*** (0.059) | | | |
| Spain | | | 0.108* (0.060) | | | |
| Italy | | | 0.115** (0.057) | | | |
| France | | | -0.052 (0.060) | | | |
| Denmark | | | -0.222*** (0.063) | | | |
| Switzerland | | | -0.362*** (0.067) | | | |
| Belgium | | | -0.086 (0.055) | | | |
| Constant | -4.145*** (0.082) | -4.101*** (0.090) | -3.958*** (0.100) | -4.054*** (0.108) | -4.101*** (0.090) | -4.132*** (0.107) |
| R^2 | 0.0758 | 0.078 | 0.109 | 0.111 | 0.0778 | 0.056 |
| Observations | 13,292 | 13,292 | 13,292 | 13,292 | 13,292 | 13,292 |
| Country | All | All | All | All | All | All |
| Dummy Var./other | None | Wave | Wave + country | Countrywave + wave | Wave (plus RE) | FE + wave |
| Gender | male | male | male | male | male | male |
| Age restr. | 90 | 90 | 90 | 90 | 90 | 90 |
| Individuals | 3,332 | 3,332 | 3,332 | 3,332 | 3,332 | 3,332 |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of health deficits is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

size of our coefficients is changed due to the addition of this extra variable that inherently also implies a larger sample size. Results can be found in the Appendix (Tables 15 and 16). Then we also included an interaction between the age variable and the extra variable and in none of the cases was this interaction significant. These exercises suggest that our results are not biased due to the consideration of only the people alive.

2.3. Non-Linear Estimation Results. We next abandon the log-linear specification and estimate an exponential relationship of the Gompertz-Makeham structure. This approach is inspired by Mitnitski et al. (2002a) who argued in favor of such a specification based on the conceptual similarity of aging understood as health deficit accumulation and aging understood as increasing

mortality. If health deficits are accumulated in Gompertz-Makeham fashion, then ignoring the Makeham-term would indeed seriously bias the results, as shown by Gavrilov and Gavrilova (1991). We thus proceed by estimating the following equation:

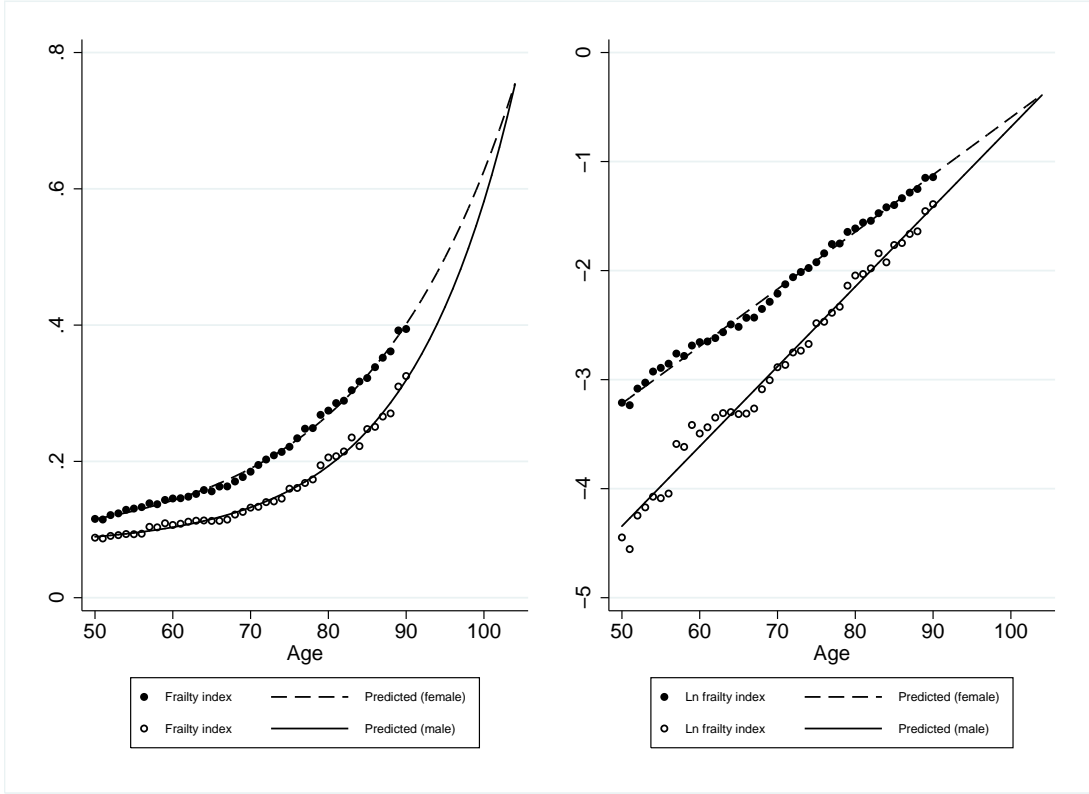
$$D_{igw} = A_{gw} + R_{gw} \cdot \exp(\alpha_{gw} \cdot age_{iwg}) + \epsilon_{igw} \quad (2)$$

where w is an index for waves in the following exercise and it will be replaced by c (country) in the subsequent one; ϵ is the error term.

For linguistic convenience we call the term A “Makeham-term” and the terms α and R “Gompertz-terms”. The meaning of these terms, however, is different from the original mortality studies. There, the outcome variable is incidence (mortality risk) whereas here the outcome variable is prevalence (of health deficits). The difference matters in particular for the “Makeham-term”. Diagrammatically, an increase of A implies approximately a parallel upward shift of the health deficit curve. Analogously to the mortality studies, we can think of A as measuring environmental factors that influence health deficits independently from age. Another possibility is that A reflects (country-specific) health care institutions, given that access to and quality of health care is independent from age. Incidence, i.e. the occurrence of new health deficits, is independent from A . This can be seen by differentiating the prevalence of health deficits, $D(t) = A + R \exp(\alpha t)$, with respect to age t , which provides $\dot{D}(t) = \alpha R \exp(\alpha t)$. This means that the incidence rate \dot{D}/D is declining in A , in contrast to the original mortality studies where a larger Makeham term increases the incidence rate.

In order to get reliable estimates we bin individuals in one-year age groups (i index). Although there is a significant level of variation across individuals of the same age in their health deficits, as we can see in the upcoming analysis, the age and the average level of health deficits of individuals by age group show a stable and consistent relationship. We first analyze the relationship between the health deficit index and age by gender across all waves and all countries. Results are reported in column (1) of Table 3. The estimated Makeham-term (A) is about the same for both males and females and significantly different from zero. We take this as a first indication that the log-specification (1), which neglects the Maketerm term, is indeed misspecified. Men start out healthier than women (lower R_m than R_f) but age subsequently faster (higher α_m than α_f). Figure 1 (left-hand side) shows the data points and the predicted association between age and health deficits.

FIGURE 1: ADJUSTED HEALTH DEFICITS, ALL DATA UP TO 90 YEARS OF AGE



As a precursor of the analysis in Section ?? we show in Figure 1 (right-hand side) the association between the age-dependent rate of deficit accumulation, $\log(D_{ig} - A_g)$, and age for gender $g = f, m$. The association of adjusted health deficits and age is close to log-linear and the age-trajectories intersect at age 104. When we restrict the sample to individuals ages 85 or less we obtain similar results (intersection at 103 years of age; estimates in the Appendix (Section ??)).

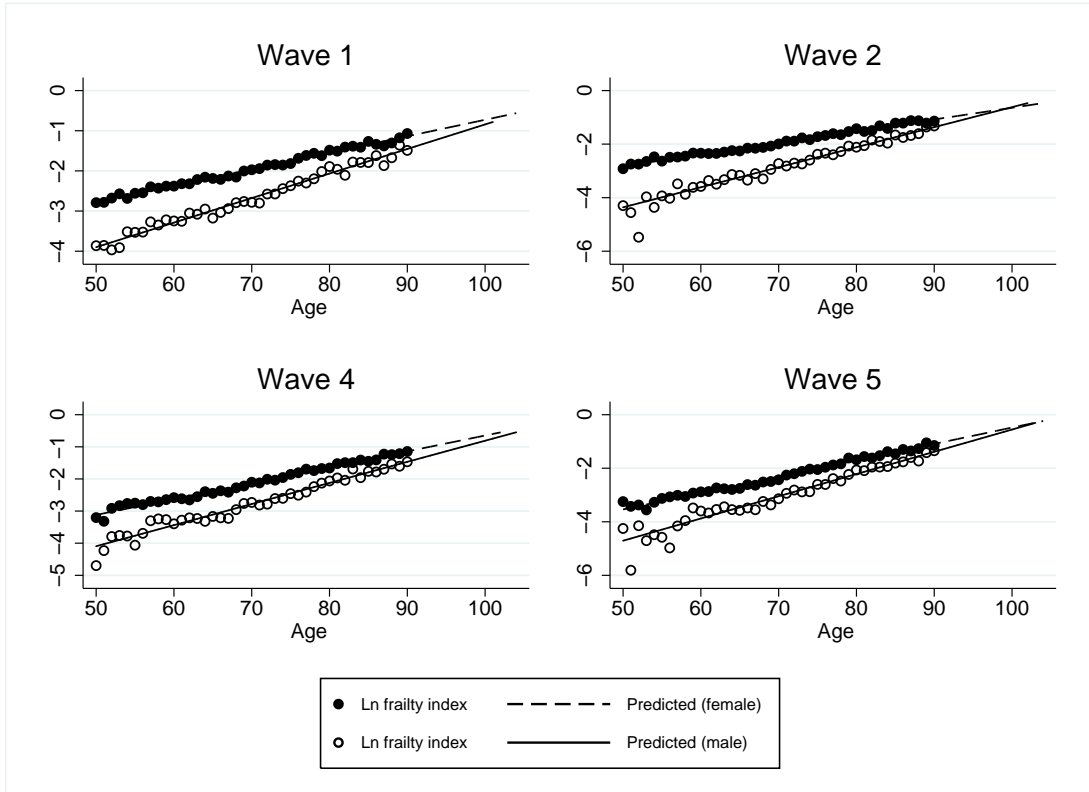
In Table 3 we show the results of the non-linear regressions by wave. In any wave, women start out less healthy ($R_f > R_m$) and develop new health deficits at a lower pace than men ($\alpha_f < \alpha_m$). The Makeham term A is significantly different from zero and about the same for both genders, aside from wave 2. In contrast to the OLS results we now observe clear time trends in the data. For both, men and women, the Gompertz term R is declining over time while the Gompertz term α is increasing over time (aside of wave 2 for men). Moreover the Makeham term A is increasing over time (aside of wave 2 for men). Overall, the model has high predictive power as indicated by the R^2 s above 98 percent.

TABLE 3: NON-LINEAR LEAST SQUARES, BY WAVE.

| | (1) | (2) | (3) | (4) | (5) |
|--------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|
| A_f | 0.0754*** (0.0049) | 0.0542*** (0.0168) | 0.0491*** (0.0170) | 0.0773*** (0.0090) | 0.0833*** (0.0088) |
| R_f | 0.0029*** (0.0005) | 0.0080** (0.0035) | 0.0067** (0.0031) | 0.0037*** (0.0012) | 0.0014** (0.0006) |
| α_f | 0.0525*** (0.0019) | 0.0411*** (0.0045) | 0.0436*** (0.0047) | 0.0494*** (0.0032) | 0.0611*** (0.0043) |
| R^2 | 0.997 | 0.982 | 0.980 | 0.991 | 0.985 |
| A_m | 0.0764*** (0.0035) | 0.0658*** (0.0098) | 0.0723*** (0.0055) | 0.0778*** (0.0068) | 0.0809*** (0.0044) |
| R_m | 0.0003*** (0.0001) | 0.0009 (0.0006) | 0.0003** (0.0001) | 0.0006* (0.0003) | 0.0001** (6.46e-05) |
| α_m | 0.0732*** (0.0033) | 0.0611*** (0.0069) | 0.0748*** (0.0051) | 0.0657*** (0.0056) | 0.0830*** (0.0050) |
| R^2 | 0.992 | 0.963 | 0.982 | 0.977 | 0.983 |
| Observations | 41 | 41 | 41 | 41 | 41 |
| Wave | all | 1 | 2 | 4 | 5 |

Notes: Standard errors reported in parenthesis. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level.

FIGURE 2: ADJUSTED HEALTH DEFICITS AND AGE BY WAVE



In Figure 2 we show the association between the log of adjusted health deficits $D_{ig} - A_g$ and age per wave. In any wave, men (white dots) start out healthier than women (black dots) such that an intersection of the age trajectories exists at some high age around 103. In the Appendix,

TABLE 4: NON-LINEAR LEAST SQUARES, BY COUNTRY.

| Variables | (1) A_f | (2) R_f | (3) α_f | (4) R^2 | (5) A_m | (6) R_m | (7) α_m | (8) Observations | (9) R^2 |
|-------------|-----------------------|-----------------------|-----------------------|--------------|-----------------------|------------------------|-----------------------|---------------------|--------------|
| Austria | 0.0449* (0.0227) | 0.00608 (0.0038) | 0.0451*** (0.0064) | 0.965 | 0.0854*** (0.0113) | 0.000575 (0.00052) | 0.0661*** (0.0098) | 41 | 0.931 |
| Germany | 0.0884*** (0.0140) | 0.0015 (0.0009) | 0.0605*** (0.0067) | 0.965 | 0.0941*** (0.0117) | 0.0002 (0.0002) | 0.0802*** (0.0124) | 41 | 0.905 |
| Sweden | 0.0921*** (0.0070) | 0.0005* (0.0003) | 0.0695*** (0.0059) | 0.974 | 0.0703*** (0.0064) | 8.18e-05 (7.37e-05) | 0.0867*** (0.0100) | 41 | 0.940 |
| Netherlands | 0.0960*** (0.0119) | 0.0014 (0.0010) | 0.0565*** (0.0077) | 0.953 | 0.0863*** (0.0071) | 2.85e-05 (4.36e-05) | 0.0955*** (0.0171) | 41 | 0.853 |
| Spain | 0.0114 (0.0194) | 0.0169*** (0.0050) | 0.0371*** (0.0029) | 0.992 | 0.0730*** (0.0108) | 0.00051 (0.00033) | 0.0724*** (0.0071) | 41 | 0.965 |
| Italy | 0.0349 (0.0281) | 0.0087* (0.0047) | 0.0448*** (0.0056) | 0.972 | 0.0417* (0.0071) | 0.00259 (0.0020) | 0.0542*** (0.0081) | 41 | 0.947 |
| France | 0.0963*** (0.0084) | 0.00152** (0.0006) | 0.0585*** (0.0044) | 0.985 | 0.0620*** (0.0097) | 0.00105* (0.0006) | 0.0614*** (0.0062) | 41 | 0.970 |
| Denmark | 0.0777*** (0.0113) | 0.0011 (0.0008) | 0.0601*** (0.0074) | 0.957 | 0.0694*** (0.0050) | 8.28e-05 (5.15e-05) | 0.0881*** (0.0069) | 41 | 0.971 |
| Switzerland | 0.0610*** (0.0131) | 0.00275 (0.0018) | 0.0481*** (0.0069) | 0.959 | 0.0740*** (0.0084) | 1.31e-05 (2.36e-05) | 0.106*** (0.0202) | 41 | 0.823 |
| Belgium | 0.1110*** (0.0058) | 0.0010*** (0.0003) | 0.0641*** (0.0034) | 0.991 | 0.0938*** (0.0052) | 0.0001 (8.53e-05) | 0.0816*** (0.0069) | 41 | 0.969 |

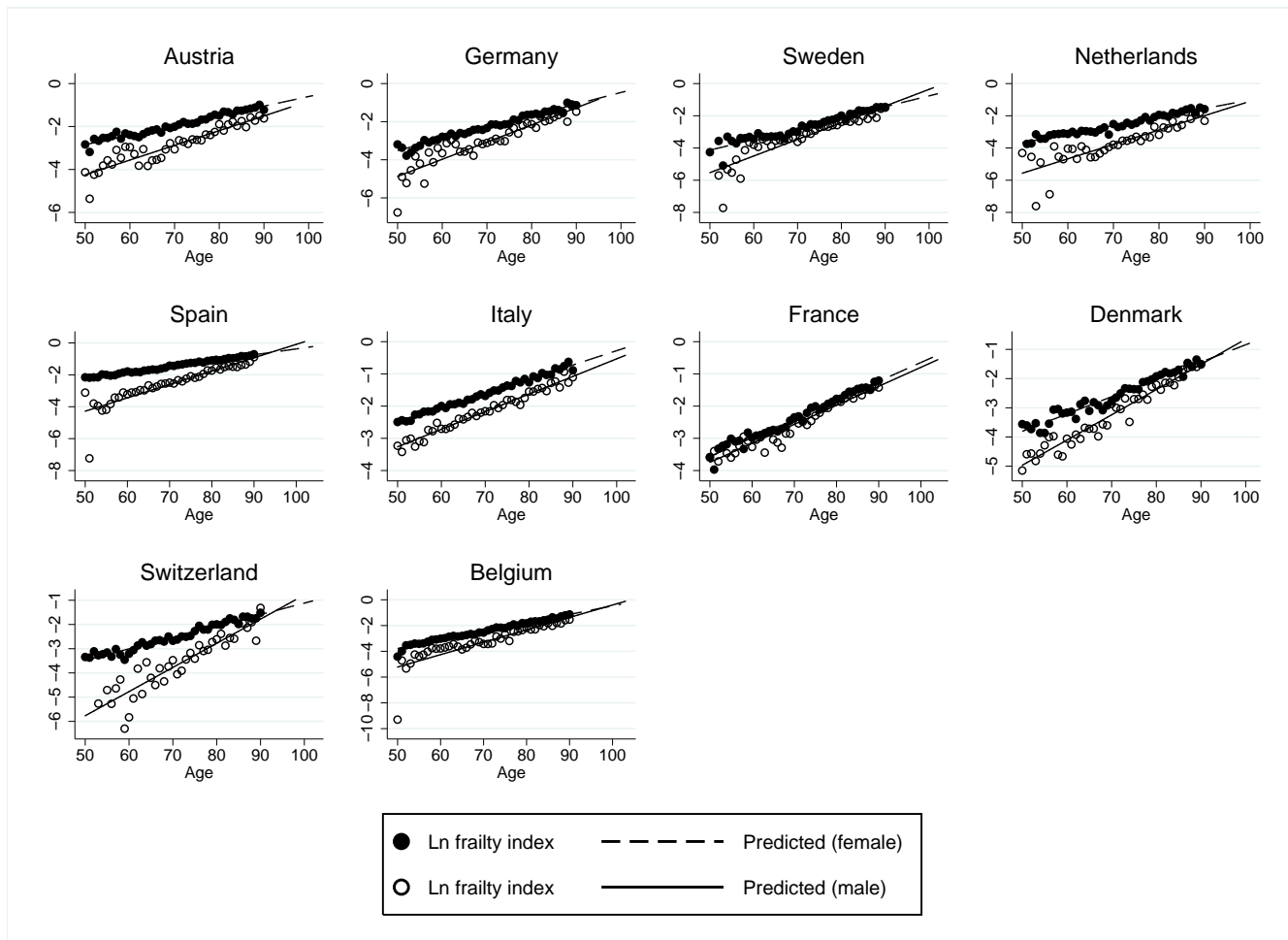
Notes: Standard errors reported in parenthesis. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level.

Section ??), we show these figures for the 85 years cutoff. Although the precise estimates per country differ somewhat, the general patterns remain the same.

In Table 4 we show results by country. In contrast to the results by wave, the pace of health deficit accumulation (α) is not always estimated to be significantly different from zero because the point estimates are close to zero and we have only 41 data points. The overall precision of the estimates, however, is high, as indicated by the R^2 above 95 percent (in most of the cases). In every country, men start out initially healthier ($R_m < R_f$) but age subsequently faster ($\alpha_m > \alpha_f$). The highest rate of health deficit accumulation is observed for men in Switzerland and for women in Sweden, while the lowest rate is observed for men in Italy and for women in Spain. Figure 3 shows the adjusted health deficit index by age for all countries. We see that

everywhere initially healthier women (black dots) age more slowly than men (white dots) such that the age trajectories intersect at some high age around 100.⁸

FIGURE 3: COMPENSATION LAW OF DEFICIT ACCUMULATION BY COUNTRY



Despite their larger number of health deficits at any age, women die later than men, a feature known as the morbidity-mortality paradox (Kulminsky et al., 2008). As a potential explanation it has been suggested that women are more likely to suffer from acute illnesses and nonfatal chronic conditions (like arthritis, constipation, headaches, and migraines) which lead to poorer health but contribute little to the risk of death (Bird and Rieker, 1999; Case and Paxson, 2005). Moreover, women engage less in risk-taking health behaviors, eat healthier, and utilize health care services more frequently than men (Waldron, 1985; Wardle et al., 2004). As a result,

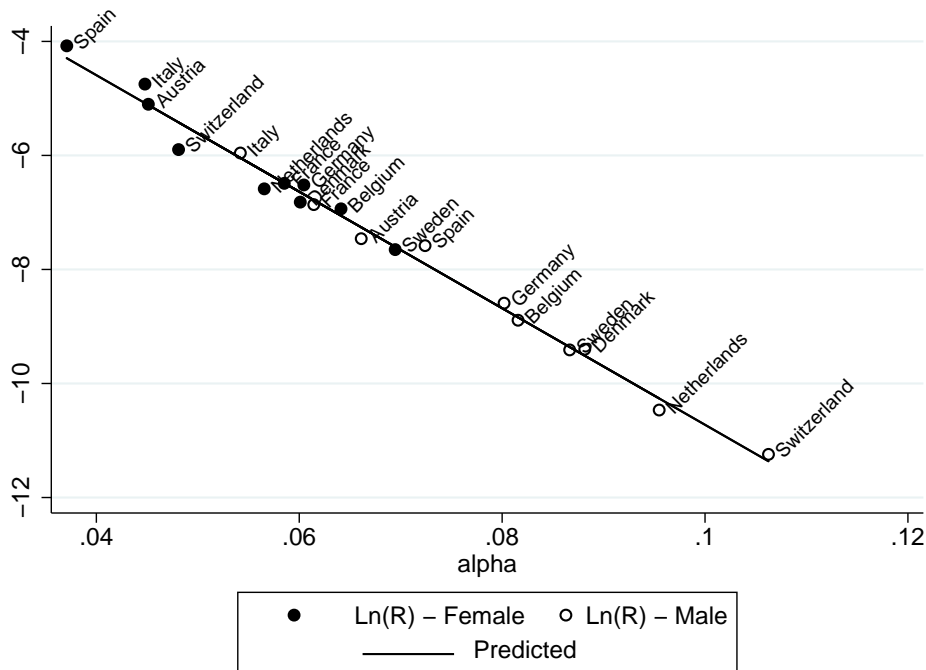
⁸In the Appendix we show the Figures for the non-linear estimates and the 85 years cutoff. Although the precise estimates per country differ, the general patterns remain the same.

women suffer more from non-fatal health deficits and develop fatal health deficits later in life (Verbrugge, 1985; Schuenemann et al., 2017).

3. THE COMPENSATION EFFECT OF DEFICIT ACCUMULATION

As shown in Tables 3 and 4 and Figures 1-3 (and previously for Canadians by Mitnitski et al., 2002a), men have initially less health deficits than women and age subsequently faster. Formally, for men, R is estimated to be smaller and α is estimated to be larger than for women. This means that, diagrammatically, the health deficit trajectories of men and women meet at a certain age. Likewise, countries, where men or women start out initially healthier (lower R) display higher rates of health deficit accumulation (higher α), see Tables 3 and 4. As shown in Figure 4, the negative relationship between α and $\ln(R)$ appears to be close to linear across countries for men and women.

FIGURE 4: COMPENSATION EFFECT FOR COUNTRY ESTIMATES



We next explore the compensation of better initial health with subsequently faster aging more formally. Inspired by the literature on the compensation effect of mortality (Gavrilov and Gavrilova, 1991), and following Mitnitski et al. (2002a), we regress α on $\ln(R)$ across countries using the pooled data:

$$\ln(R_{cg}) = \beta - B\alpha_{cg}, \quad (3)$$

in which c represents the country. The results are shown in Table 5. The point estimate of B is around 102 (column (1)). Column (2) shows the same regression but controlling for the gender of the original data points. We observe that the female dummy is not statistically significant and the point estimate of B (in absolute value) increases slightly, although it is not statistically different from the previous one. Moreover, the adjusted R^2 also remains the same and the Akaike (AIC) and the Bayesian (BIC) information criteria get smaller suggesting that the model estimated in column (1) is more appropriate for the data. Column (3) builds from the previous model and adds an interaction dummy between α and female to see whether there is a difference in the slope. Neither the female dummy nor the interaction term is statistically significant. The point estimate for B remains at 102. The adjusted R^2 is close to the previously reported ones and the information criteria suggest that the model estimated in column (1) is the preferred one. Therefore, the estimates imply that men and women across countries share an average lifespan of about 102 years with a standard deviation of 2.6 years. The overall precision of the preferred estimate is quite high, as indicated by the R^2 above 98 percent.

TABLE 5: COMPENSATION EFFECT REGRESSION.

| | (1) | (2) | (3) |
|------------------|-----------------------|-----------------------|-----------------------|
| B | 102.200*** (2.644) | 103.445*** (3.778) | 102.080*** (4.571) |
| β | -0.504** (0.183) | -0.389 (0.307) | -0.497 (0.369) |
| Female | | -0.063 (0.134) | 0.228 (0.542) |
| Female* α | | | -4.739 (8.516) |
| Unit | countries | countries | countries |
| R^2 (adjusted) | 0.987 | 0.987 | 0.988 |
| AIC | -3.788 | -2.049 | -0.432 |
| BIC | -1.797 | 0.938 | 3.551 |
| Observations | 20 | 20 | 20 |

Notes: Standard errors reported in parenthesis. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level.

The implications of these results can best be seen by inserting Equation ?? in Equation ?. Leaving aside the individual subscripts and using the transformation $\bar{D} = \log(\beta)$ this provides

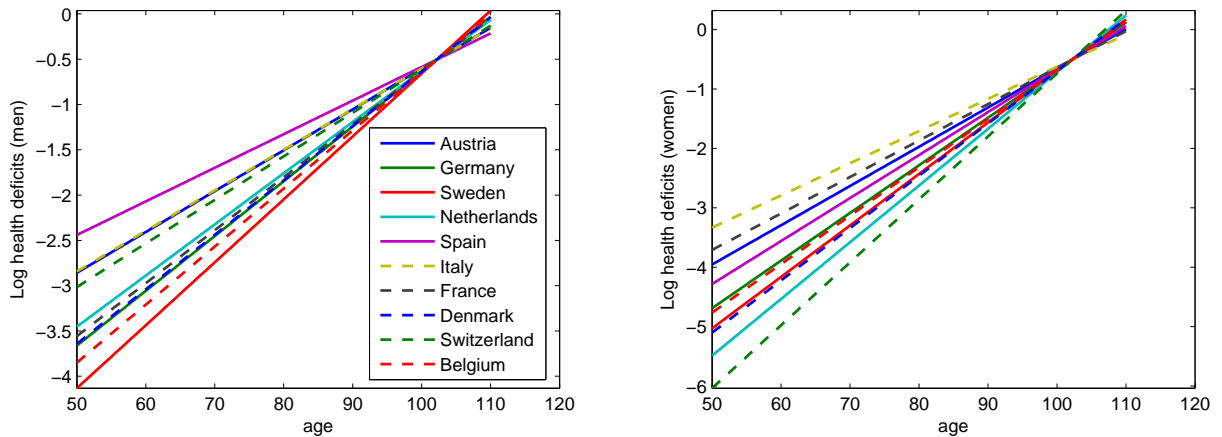
$$D_{cg} - A_{cg} = \bar{D}e^{\alpha_{cg}(age_{cg} - B)}. \quad (4)$$

On the left hand side of Equation ?? we have the age-dependent part of the health deficit index (D corrected by the age-independent Makeham term A). Equation ?? suggests that there exists a common age, namely B at which age-dependent health deficits are the same, namely \bar{D} , across the European countries. The health deficits \bar{D} are given by the point estimates of \bar{D} as $\exp(-0.504) = 0.604$. The point estimate is statistically different from zero, at the 5% level.

Interestingly, our estimates of \bar{D} correspond with the estimated upper limit of health deficit accumulation by Rockwood and Mitnitski (2006) and Bennet et al. (2013). To see this, add the average estimated Makeham term A_g from Table 3 (of about 0.075) to \bar{D} to obtain 0.68. The previous studies had suggested that there exists an upper (attainable) limit of the health deficit index of about 0.7. In light of the literature on human lifespan and the compensation effect of mortality (Gavrilov and Gavrilova, 1991) it is thus tempting to identify the common age of deficit accumulation B as an estimate of human lifespan.

Finally we discuss the implication of our findings for comparative aging across Europe. For that purpose we feed into Equation ?? the country- and gender-specific estimates of α from Table 4. The results are shown in Figure 5. Along the ordinate we measure age-dependent health deficits ($D - A$) in logs. For better visibility we split the sample between men (left hand side) and women (right hand side). We see that Spanish men are the least healthy in our European sample, next to the Italian and Austrians, while Swedish men are the healthiest, next to Belgian and German men. Initially healthier men are aging faster subsequently in a way such that all trajectories intersect at a common age of 102.

FIGURE 5: AGING IN EUROPE: MEN (LEFT) AND WOMEN (RIGHT)



The figure shows age-dependent health deficits ($D - A$) across countries, according to Equation ?? when the country-specific force of aging α_{ig} is fed in from the estimates of Table 4.

Structurally, we observe the same picture for women albeit with a somewhat different country ranking. Among women, Italians are the least healthy, next to French and Austrian woman. Swiss women are the healthiest next to the Dutch and Swedish. As for men, women in initially healthier countries accumulate additional health deficits faster such that a common intersection at age 102 emerges.

4. CONCLUSION

In this study we showed in non-linear regressions the differences and similarities of health deficit accumulation of European men and women. We showed that the consideration of a constant (age-independent) “Makeham”-term leads to substantially higher estimates of the rate at which additionally health deficits are accumulated with increasing age and that it resolves some previously inconclusive results on aging of men and women. Across countries (and waves of our sample) men are found to be initially healthier than women but to age faster (at a rate of 7.3 percent compared to 5.2, according to our point estimates). A similar compensation effect of health deficit accumulation is found across the European countries. Countries in which men or women are initially healthier, display higher rates of aging, in terms of health deficit accumulation. This implies convergence and we estimated a focal point at age 102 where individuals, on average, age in the same way across gender and across countries. Our sample, however, consists exclusively of fully developed European countries. It would be interesting to see whether the compensation effect of deficit accumulation prevails in a more heterogenous sample or whether, for example, a North-South gradient of focal points emerges.

Since health deficits at the focal point coincide with estimates of an attainable upper limit of health deficit accumulation, it is tempting to associate the population-invariant age at the focal point with human life span. In this context, it is interesting that previous studies based on mortality rates suggested a shorter human life span of around 95 years (Gavrilov and Gavrilova, 1991; Strulik and Vollmer, 2013). Of course, the estimates from mortality rates are not one-to-one comparable to our estimates from morbidity rates, although there exists a close association between biological markers and age as determinants of mortality (see Mitnitski et al. 2002b). Another difference is sample size. Compared to mortality data, which is available for whole populations, the SHARE data is rather limited. Although the huge variability of individual aging (as a stochastic process) can be smoothed out by averaging, we had to omit the oldest

old because of limited representation in the sample. Rather than emphasizing point estimates it seems thus prudent to conclude with highlighting the qualitative result of structural similarity of health deficit accumulation across the European countries. These results suggest convergence of initially disperse health deficits and the existence of a focal point as a potential invariant of human aging.

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6. APPENDIX

6.1. Health Deficit Index.

TABLE 6: ITEMS OF THE HEALTH DEFICIT INDEX

| | |
|-----------------------------------|--------------------------------------|
| Arthritis | Difficulties concentrating |
| Stroke | Difficulties shopping |
| Parkinson | Difficulties lifting 5kg |
| Diabetes | Difficulties pulling/pushing object |
| Cholesterol | Less enjoyment |
| Asthma | Difficulties managing money |
| Depressed | Difficulties joining activities |
| High blood pressure | Difficulties bathing |
| Cataracts | Difficulties dressing |
| Pain | Difficulties doing housework |
| Difficulties seeing arm length | Difficulties walking across house |
| Difficulties seeing across street | Difficulties eating |
| Difficulties sitting long | Difficulties getting out of bed |
| Difficulties walking 100mt | Difficulties using the toilet |
| Difficulties getting out chair | Difficulties using map |
| Difficulties climbing stairs | Walking speed (only in wave 1 and 2) |
| Difficulties kneeling | BMI |
| Difficulties picking an object | Grip strength |
| Difficulties extending arms | Mobility |

TABLE 7: VARIABLES FROM THE SHARE DATA.

| Dimension | Variable | Coding in SHARE dataset |
|---|--------------------|--|
| Arthritis | ph006d8 | yes=1, no=0 |
| Stroke | ph006d4 | yes=1, no=0 |
| Parkinson | ph006d12 | yes=1, no=0 |
| Diabetes | ph006d5 | yes=1, no=0 |
| Cholesterol | ph006d3 | yes=1, no=0 |
| Asthma | ph006d7 | yes=1, no=0 |
| Depressed | mh002. | yes=1, no=1 |
| High blood pressure | ph006d2 | yes=1, no=0 |
| Cataracts | ph006d13 | yes=1, no=0 |
| Pain | ph010d1 | yes=1, no=0 |
| Difficulties seeing arm length | ph044. | none=0, mild=0.25, moderate=0.5, bad=0.75, very bad=1 |
| Difficulties seeing across street | ph043. | none=0, mild=0.25, moderate=0.5, bad=0.75, very bad=1 |
| Difficulties sitting long | ph048d2 | yes=1, no=0 |
| Difficulties walking 100mt | ph048d1 | yes=1, no=0 |
| Difficulties getting out chair | ph048d3 | yes=1, no=0 |
| Difficulties climbing stairs | ph048d5 | yes=1, no=0 |
| Difficulties kneeling | ph048d6 | yes=1, no=0 |
| Difficulties picking an object | ph048d10 | yes=1, no=0 |
| Difficulties extending arms | ph048d7 | yes=1, no=0 |
| Difficulties concentrating | mh014. | yes=1, no=0 |
| Difficulties shopping | ph049d9 | yes=1, no=0 |
| Difficulties lifting 5kg | ph048d9 | yes=1, no=0 |
| Difficulties pulling/pushing object | ph048d8 | yes=1, no=0 |
| Less enjoyment | mh016. | yes=1, no=0 |
| Difficulties managing money | ph049d13 | yes=1, no=0 |
| Difficulties joining activities (because of health) | ph005. | not limited=0, limited, not severely=0.5, severely limited=1 |
| Difficulties bathing | ph049d3 | yes=1, no=0 |
| Difficulties dressing | ph049d1 | yes=1, no=0 |
| Difficulties doing housework | ph049d12 | yes=1, no=0 |
| Difficulties walking across the house | ph049d2 | yes=1, no=0 |
| Difficulties eating | ph049d4 | yes=1, no=0 |
| Difficulties getting out of bed | ph049d5 | yes=1, no=0 |
| Difficulties using the toilet | ph049d6 | yes=1, no=0 |
| Difficulties using map | ph049d7 | yes=1, no=0 |
| Walking Speed (only available wave 1 and wave 2) | wspeed and wspeed2 | no problem if: aged<75 (by construction);(wspeed>=0.4 or wspeed2==0); problem if: wspeed<=0.4 or wspeed2==1 |
| BMI | bmi | (bmi<=18 or bmi>=30) =1; (bmi>=25 and bmi<30)=0.5; bmi>18.5 and bmi<25)=0 |
| Grip strength | maxgrip and bmi | it is recorded as frail for women if (maxgrip<=29 & bmi<=24); (maxgrip<=30 & (bmi>=24.1 & bmi<=28)); (maxgrip<=32 & bmi>28); for men if : (maxgrip<=29 & bmi<=24); (maxgrip<=30 & (bmi>=24.1 & bmi<=28)); (maxgrip<=32 & bmi>28) |
| Mobility | mobility | (mobility>=3)=1; (1>=mobility<3)=0.5 and mobility=0 |

6.2. Summary statistics.

TABLE 8: OBSERVATIONS PER WAVE AND GENDER

| Wave | Female | Male | Ratio |
|-------|--------|--------|-------|
| 1 | 13,021 | 10,974 | 1.187 |
| 2 | 13,180 | 11,019 | 1.196 |
| 4 | 19,183 | 15,677 | 1.224 |
| 5 | 25,051 | 21,036 | 1.191 |
| Total | 70,435 | 58,706 | 1.200 |

TABLE 9: OBSERVATIONS BY COUNTRY AND GENDER. LEFT: FULL SAMPLE. RIGHT: PANEL

| Country | Female | Male | Ratio | Country | Female | Male | Ratio |
|-------------|--------|--------|-------|-------------|--------|--------|-------|
| Austria | 6,854 | 5,055 | 1.356 | Austria | 1,020 | 668 | 1.527 |
| Germany | 6,657 | 5,966 | 1.111 | Germany | 1,288 | 1,044 | 1.044 |
| Sweden | 6,442 | 5,613 | 1.189 | Sweden | 1,816 | 1,344 | 1.340 |
| Netherlands | 6,647 | 5,589 | 1.46 | Netherlands | 1,956 | 1,340 | |
| Spain | 7,966 | 6,630 | 1.202 | Spain | 1,820 | 1,272 | 1.431 |
| Italy | 7,352 | 6,153 | 1.195 | Italy | 2,312 | 1,768 | 1.308 |
| France | 8,734 | 6,833 | 1.278 | France | 1,936 | 1,356 | 1.428 |
| Denmark | 5,511 | 4,805 | 1.147 | Denmark | 1,288 | 1,092 | 1.180 |
| Switzerland | 4,871 | 4,113 | 1.184 | Switzerland | 896 | 688 | 1.302 |
| Belgium | 9,401 | 7,949 | 1.183 | Belgium | 3,268 | 2,604 | 1.257 |
| Total | 70,435 | 58,706 | 1.200 | Total | 17,596 | 13,292 | 1.324 |

TABLE 10: PANEL ANALYSIS SAMPLE, BY WAVE.

| Wave | All | | | Females | | | Males | | |
|------|------|-----------|-----------|----------|-----------|-----------|----------|-----------|-----------|
| | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. |
| 1 | 7722 | 0.140 | 0.107 | 4399.000 | 0.165 | 0.114 | 3323.000 | 0.107 | 0.085 |
| 2 | 7722 | 0.145 | 0.112 | 4399.000 | 0.170 | 0.119 | 3323.000 | 0.113 | 0.092 |
| 4 | 7722 | 0.174 | 0.131 | 4399.000 | 0.201 | 0.138 | 3323.000 | 0.138 | 0.112 |
| 5 | 7722 | 0.182 | 0.152 | 4399.000 | 0.208 | 0.155 | 3323.000 | 0.148 | 0.140 |

TABLE 11: PANEL ANALYSIS SAMPLE, BY COUNTRY.

| Country | All | | | Females | | | Males | | |
|-------------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. |
| Austria | 1688 | 0.166 | 0.129 | 1020.000 | 0.183 | 0.131 | 668.000 | 0.138 | 0.121 |
| Germany | 2332 | 0.157 | 0.115 | 1288.000 | 0.176 | 0.122 | 1044.000 | 0.133 | 0.101 |
| Sweden | 3156 | 0.133 | 0.103 | 1816.000 | 0.153 | 0.107 | 1340.000 | 0.107 | 0.093 |
| Netherlands | 3416 | 0.135 | 0.104 | 1956.000 | 0.158 | 0.110 | 1460.000 | 0.104 | 0.085 |
| Spain | 3092 | 0.216 | 0.164 | 1820.000 | 0.257 | 0.171 | 1272.000 | 0.159 | 0.134 |
| Italy | 4080 | 0.194 | 0.146 | 2312.000 | 0.225 | 0.149 | 1768.000 | 0.154 | 0.132 |
| France | 3288 | 0.165 | 0.126 | 1932.000 | 0.187 | 0.127 | 1356.000 | 0.132 | 0.118 |
| Denmark | 2380 | 0.132 | 0.110 | 1288.000 | 0.150 | 0.109 | 1092.000 | 0.110 | 0.106 |
| Switzerland | 1584 | 0.113 | 0.084 | 896.000 | 0.129 | 0.087 | 688.000 | 0.093 | 0.075 |
| Belgium | 5872 | 0.158 | 0.124 | 3268.000 | 0.187 | 0.131 | 2604.000 | 0.122 | 0.102 |
| Total | 30888 | 0.160 | 0.128 | 17596.000 | 0.186 | 0.134 | 13292.000 | 0.127 | 0.111 |

TABLE 12: ALL SAMPLE, BY WAVE.

| Wave | All | | | Females | | | Males | | |
|-------|---------|-----------|-----------|---------|-----------|-----------|--------|-----------|-----------|
| | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. |
| 1 | 23,995 | 0.154 | 0.129 | 13,021 | 0.179 | 0.136 | 10,974 | 0.125 | 0.113 |
| 2 | 24,199 | 0.154 | 0.133 | 13,180 | 0.178 | 0.141 | 11,019 | 0.126 | 0.118 |
| 4 | 34,860 | 0.166 | 0.138 | 19,183 | 0.189 | 0.144 | 15,677 | 0.138 | 0.124 |
| 5 | 46,087 | 0.158 | 0.144 | 25,051 | 0.180 | 0.150 | 21,036 | 0.132 | 0.133 |
| Total | 129,141 | 0.159 | 0.138 | 70,435 | 0.182 | 0.144 | 58,706 | 0.131 | 0.124 |

TABLE 13: ALL SAMPLE, BY COUNTRY.

| Country | All | | | Females | | | Males | | |
|-------------|---------|-----------|-----------|---------|-----------|-----------|--------|-----------|-----------|
| | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. |
| Austria | 11,909 | 0.163 | 0.140 | 6,854 | 0.179 | 0.144 | 5,055 | 0.141 | 0.132 |
| Germany | 12,623 | 0.160 | 0.133 | 6,657 | 0.178 | 0.138 | 5,966 | 0.141 | 0.123 |
| Sweden | 12,055 | 0.135 | 0.118 | 6,442 | 0.154 | 0.119 | 5,613 | 0.113 | 0.112 |
| Netherlands | 12,236 | 0.136 | 0.116 | 6,647 | 0.160 | 0.124 | 5,589 | 0.109 | 0.098 |
| Spain | 14,596 | 0.202 | 0.171 | 7,966 | 0.236 | 0.177 | 6,630 | 0.162 | 0.154 |
| Italy | 13,505 | 0.186 | 0.156 | 7,352 | 0.215 | 0.163 | 6,153 | 0.151 | 0.140 |
| France | 15,567 | 0.163 | 0.133 | 8,734 | 0.186 | 0.138 | 6,833 | 0.133 | 0.121 |
| Denmark | 10,316 | 0.126 | 0.120 | 5,511 | 0.144 | 0.125 | 4,805 | 0.106 | 0.111 |
| Switzerland | 8,984 | 0.118 | 0.097 | 4,871 | 0.133 | 0.101 | 4,113 | 0.099 | 0.087 |
| Belgium | 17,350 | 0.166 | 0.137 | 9,401 | 0.192 | 0.144 | 7,949 | 0.134 | 0.120 |
| Total | 129,141 | 0.159 | 0.138 | 70,435 | 0.182 | 0.144 | 58,706 | 0.131 | 0.124 |

TABLE 14: ALL SAMPLE, BY BROAD AGE GROUP.

| Age group | All | | | Females | | | Males | | |
|-----------|---------|-----------|-----------|---------|-----------|-----------|--------|-----------|-----------|
| | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. | Obs. | FI (mean) | Std. Dev. |
| 50 | 39,804 | 0.115 | 0.101 | 22,473 | 0.130 | 0.107 | 17,331 | 0.097 | 0.089 |
| 60 | 44,020 | 0.137 | 0.112 | 23,359 | 0.157 | 0.117 | 20,661 | 0.114 | 0.101 |
| 70 | 30,762 | 0.188 | 0.145 | 16,186 | 0.219 | 0.148 | 14,576 | 0.152 | 0.133 |
| 80 | 14,555 | 0.281 | 0.188 | 8,417 | 0.315 | 0.185 | 6,138 | 0.234 | 0.181 |
| Total | 129,141 | 0.159 | 0.138 | 70,435 | 0.182 | 0.144 | 58,706 | 0.131 | 0.124 |

6.3. Selection tests.

TABLE 15: VARIABLE ADDITION TESTS (FEMALES).

| | (1) | (2) | (3) | (4) | (5) | (6) |
|--------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Age | 0.029*** (0.001) | 0.030*** (0.001) | 0.029*** (0.001) | 0.029*** (0.001) | 0.040*** (0.007) | |
| Wave sum | -0.178*** (0.014) | -0.170*** (0.015) | -0.163*** (0.014) | -0.163*** (0.014) | -0.004 (0.110) | |
| Age | 0.029*** (0.001) | 0.030*** (0.001) | 0.029*** (0.001) | 0.029*** (0.001) | 0.030*** (0.001) | |
| Balanced | -0.435*** (0.035) | -0.419*** (0.037) | -0.404*** (0.036) | -0.404*** (0.036) | -0.413*** (0.036) | |
| Age | 0.030*** (0.001) | 0.031*** (0.001) | 0.030*** (0.001) | 0.030*** (0.001) | 0.033*** (0.001) | 0.023*** (0.001) |
| Next wave | -0.495*** (0.051) | -0.521*** (0.052) | -0.505*** (0.050) | -0.505*** (0.050) | -0.314*** (0.036) | -0.201*** (0.038) |
| Dummy Var. | | wave | wave + country | countrywave + wave | wave (plus RE) | individual FE + wave |
| Observations | | | | 18,170 | | |
| Individuals | | | | 4,791 | | |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of health deficits is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

TABLE 16: VARIABLE ADDITION TESTS (MALES).

| | (1) | (2) | (3) | (4) | (5) | (6) |
|--------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Age | 0.026*** (0.001) | 0.025*** (0.001) | 0.025*** (0.001) | 0.025*** (0.001) | 0.025*** (0.001) | |
| Wave sum | -0.244*** (0.015) | -0.255*** (0.016) | -0.254*** (0.015) | -0.254*** (0.015) | -0.242*** (0.015) | |
| Age | 0.026*** (0.001) | 0.025*** (0.001) | 0.024*** (0.001) | 0.024*** (0.001) | 0.025*** (0.001) | |
| Balanced | -0.607*** (0.036) | -0.637*** (0.038) | -0.631*** (0.037) | -0.631*** (0.037) | -0.632*** (0.037) | |
| Age | 0.027*** (0.001) | 0.028*** (0.001) | 0.027*** (0.001) | 0.027*** (0.001) | 0.032*** (0.001) | 0.026*** (0.002) |
| Next wave | -0.704*** (0.053) | -0.760*** (0.054) | -0.747*** (0.053) | -0.746*** (0.053) | -0.464*** (0.043) | -0.261*** (0.046) |
| Dummy Var. | | wave | wave + country | countrywave + wave | wave (plus RE) | individual FE + wave |
| Observations | | | | 14,042 | | |
| Individuals | | | | 3,848 | | |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of health deficits is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

6.4. Robustness - results using 85 years cutoff.

TABLE 17: PANELS RESULTS, FEMALE BALANCED SAMPLE, UP TO 85 YEARS OF AGE.

| | (1) | (2) | (3) | (4) | (5) |
|--------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Age | 0.030*** (0.001) | 0.029*** (0.001) | 0.029*** (0.001) | 0.030*** (0.001) | 0.022*** (0.001) |
| Wave 2 | -0.063*** (0.010) | -0.060*** (0.010) | 0.047 (0.052) | -0.063*** (0.010) | -0.039*** (0.008) |
| Wave 4 | -0.008 (0.013) | -0.002 (0.013) | 0.155*** (0.051) | -0.008 (0.013) | 0.047*** (0.008) |
| Wave 5 | -0.071*** (0.016) | -0.063*** (0.015) | 0.023 (0.053) | -0.071*** (0.016) | |
| Germany | | 0.000 (0.000) | | | |
| Sweden | | 0.046 (0.048) | | | |
| Netherlands | | -0.166*** (0.046) | | | |
| Spain | | -0.060 (0.045) | | | |
| Italy | | 0.338*** (0.044) | | | |
| France | | 0.277*** (0.042) | | | |
| Denmark | | 0.065 (0.045) | | | |
| Switzerland | | -0.161*** (0.049) | | | |
| Belgium | | -0.316*** (0.053) | | | |
| Constant | -3.891*** (0.080) | -3.872*** (0.086) | -3.927*** (0.091) | -3.891*** (0.080) | -3.403*** (0.077) |
| Observations | 16,508 | 16,508 | 16,508 | 16,508 | 16,508 |
| R^2 | 0.097 | 0.153 | 0.154 | 0.0967 | 0.056 |
| Country | All | All | All | All | All |
| Dummy Var. | wave | wave + country | countrywave + wave | wave (plus RE) | individual FE + wave |
| Gender | female | female | female | female | female |
| Age restr. | 85 | 85 | 85 | 85 | 85 |
| Individuals | 4,127 | 4,127 | 4,127 | 4,127 | 4,127 |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of health deficits is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

TABLE 18: PANELS RESULTS, MALE BALANCED SAMPLE, UP TO 85 YEARS OF AGE.

| | (1) | (2) | (3) | (4) | (5) |
|--------------|----------------------|----------------------|----------------------|----------------------|-----------------------|
| Age | 0.024*** (0.002) | 0.022*** (0.002) | 0.022*** (0.002) | 0.024*** (0.002) | 0.024*** (0.002) |
| Wave 2 | -0.040*** (0.013) | -0.036*** (0.013) | -0.033 (0.072) | -0.040*** (0.013) | -0.041*** (0.011) |
| Wave 4 | 0.069*** (0.017) | 0.080*** (0.017) | 0.109 (0.072) | 0.069*** (0.017) | 0.069*** (0.011) |
| Wave 5 | 0.001 (0.020) | 0.015 (0.020) | -0.011 (0.075) | 0.001 (0.020) | |
| Germany | | -0.003 (0.064) | | | |
| Sweden | | -0.255*** (0.062) | | | |
| Netherlands | | -0.222*** (0.060) | | | |
| Spain | | 0.101* (0.061) | | | |
| Italy | | 0.109* (0.058) | | | |
| France | | -0.080 (0.062) | | | |
| Denmark | | -0.251*** (0.065) | | | |
| Switzerland | | -0.381*** (0.069) | | | |
| Belgium | | -0.092 (0.056) | | | |
| Constant | -3.984*** (0.100) | -3.799*** (0.110) | -3.883*** (0.117) | -3.984*** (0.100) | -3.993*** (0.108) |
| Observations | 12,680 | 12,680 | 12,680 | 12,680 | 12,680 |
| R^2 | 0.060 | 0.092 | 0.094 | 0.0604 | 0.052 |
| Country | All | All | All | All | All |
| Dummy Var. | wave | wave + country | countrywave + wave | wave (plus RE | individual + wave (FE |
| Gender | male | male | male | male | male |
| Age restr. | 85 | 85 | 85 | 85 | 85 |
| Individuals | 3,170 | 3,170 | 3,170 | 3,170 | 3,170 |

Notes: Robust standard errors clustered at the individual level. One asterisk indicates significance at the 10 percent level, two asterisks indicate significance at the 5 percent level, and three asterisks indicate significance at the 1 percent level. Country-wave dummies are included in column (4) but the coefficients are not reported. In columns (1) to (6) the log of health deficits is the dependent variable. Individuals with a health deficit index of 0 were dropped out of the sample. Wave 1 and Austria are the base categories.

FIGURE 6: NON-LINEAR LEAST SQUARES, ALL SAMPLE RESTRICTED TO 85

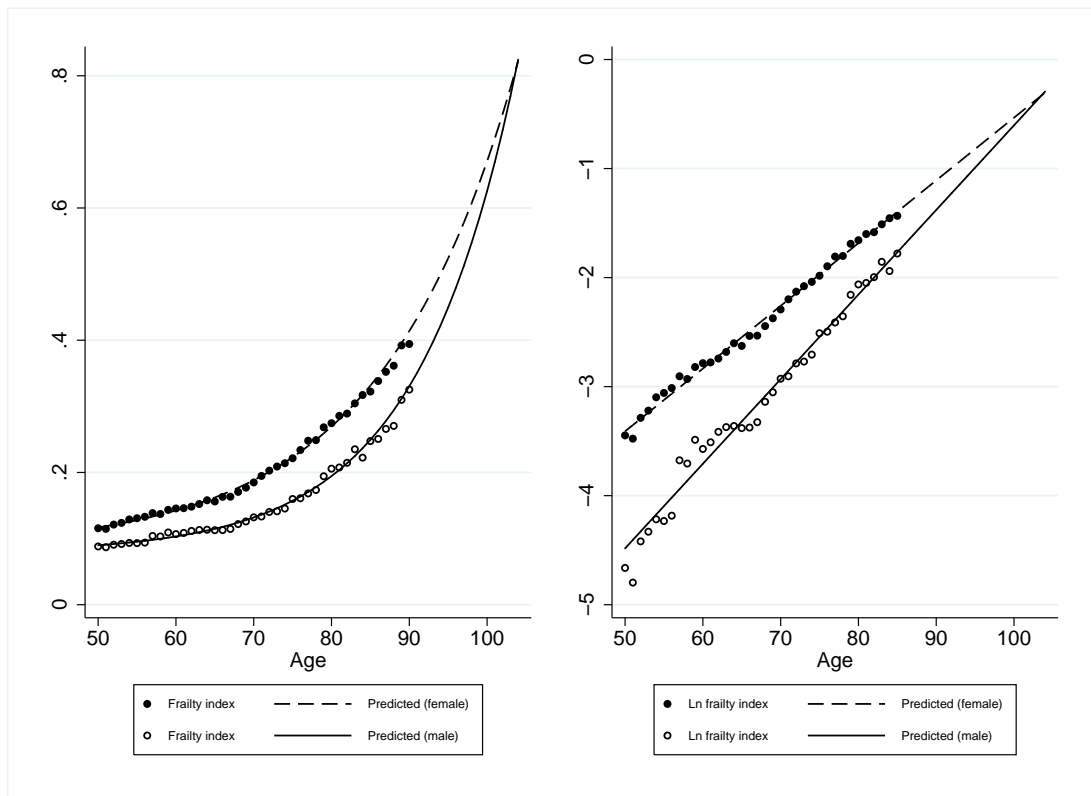


FIGURE 7: ORDINARY LEAST SQUARES BY WAVE, 85 YEARS CUTOFF

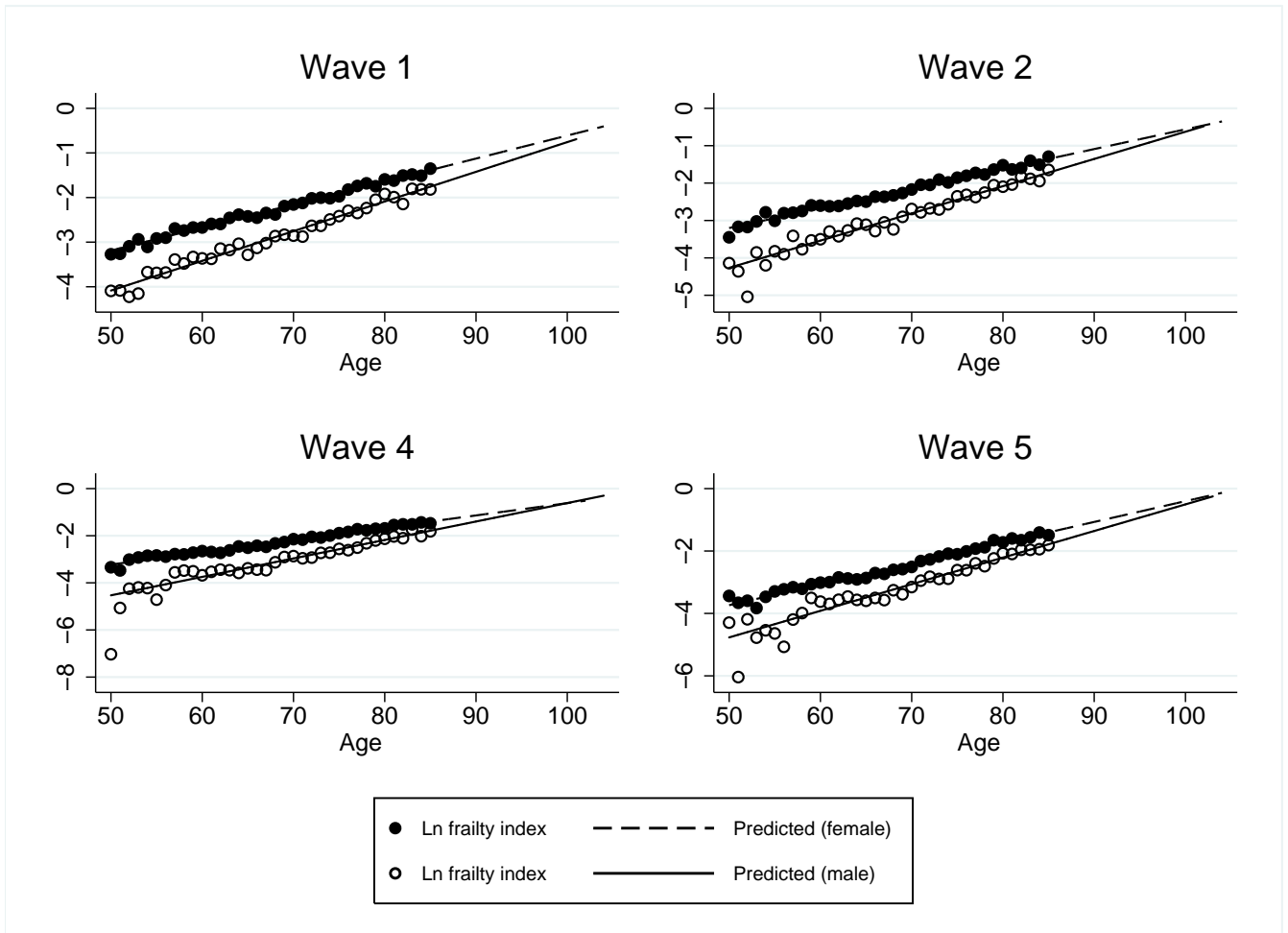


FIGURE 8: ORDINARY LEAST SQUARES BY COUNTRY, 85 YEARS CUTOFF

