Center for European, Governance and Economic Development Research

Discussion Papers

Number 301 – January 2017

HOW WE FALL APART: SIMILARITIES OF HUMAN AGING IN 10 EUROPEAN COUNTRIES

Ana Lucia Abeliansky
Holger Strulik

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

ISSN: 1439-2305

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

Ana Lucia Abeliansky[*]
Holger Strulik[**]

January 2017

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.

Keywords: health; aging; health deficit index; Europe; gender differences; compensation law, human life span.
JEL: I10, I19.

---

[*] University of Göttingen, Department of Economics, Platz der Göttinger Sieben 3, 37073 Göttingen; email: ana-lucia.abeliansky@wiwi.uni-goettingen.de
[**] University of Göttingen, Department of Economics, Platz der Göttinger Sieben 3, 37073 Göttingen, Germany; email: holger.strulik@wiwi.uni-goettingen.de.

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 103 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 human 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 $\mu(x) - A = M\mathrm{e}^{\alpha(x-B)}$, 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 Gompartz 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. (2002) 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. (2002) 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

---

[1] Originally, 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, 2002) 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

---

[2] On 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 analysis of the main text 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 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) and considered the four waves (1, 2, 4 and 5) that provide health-related information.[3] 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 and Switzerland.[4] We only kept individuals until age 90 since a significant share of older people show “super healthy” characteristics, presumably because of selection effects. While Mitnitski et al. (2002) consider individuals up to the age of 79, Harttgen et al. (2013) consider the whole age span.

---

[3] We also made use of part of the Easyshare release 2.0.0 to compile the dataset.

[4] Although 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.

Table 1: 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 kneeing	BMI
Difficulties picking an object	Grip strength
Difficulties extending arms	Mobility

For each individual we constructed a health deficit measure following Mitnitski et al. (2002) 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 1 . Details on how each variable was constructed can be found in Table 8 in the Appendix. We then constructed 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 2 shows how the observations are distributed in each wave, while Table 3 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).

Table 2: Observations per Wave and Gender

Wave	Female	Male	Ratio
1	13,091	11,049	1.185
2	13,403	11,314	1.185
4	19,614	16,185	1.212
5	25,675	21,762	1.180
Total	71,783	60,310	1.190

Table 3: Observations by Country and Gender. Left: Full Sample. Right: Panel

Country	Female	Male	Ratio
Austria	7,035	5,230	1.345
Germany	6,734	6,060	1.111
Sweden	6,584	5,801	1.135
Netherlands	6,731	5,716	1.178
Spain	8,179	6,883	1.188
Italy	7,484	6,311	1.186
France	8,943	7,070	1.265
Denmark	5,645	4,954	1.139
Switzerland	4,918	4,182	1.176
Belgium	9,530	8,103	1.176
Total	71,783	60,310	1.190

Country	Female	Male	Ratio
Austria	1,020	668	1.527
Germany	1,288	1,044	1.044
Sweden	1,816	1,344	1.340
Netherlands	1,956	1.340	
Spain	1,820	1,272	1.431
Italy	2,312	1,768	1.308
France	1,936	1,356	1.428
Denmark	1,288	1,092	1.180
Switzerland	896	688	1.302
Belgium	3,268	2,604	1.257
Total	17,596	13,292	1.324

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

$$\ln D_{igw} = r_g + \alpha_g \cdot age_{igw} + \epsilon_{igw} \tag{1}$$

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 $D_{igw} = A_g + R_g \exp(\alpha_g age_{igw})$, $R_g = \exp(r_g)$, for gender $g = f, m$.

Results are shown in Table 4 and Table 5. Column (1) shows results for the simple specification (Equation (1)). Column (2) further includes wave dummies, column (3) adds country dummies. 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 16 in the Appendix (Section 6.3) we show that we obtain similar results when the maximum age of individuals in the sample is restricted to 85 (rather than 90).

Table 4: Women Aged 90 or Younger. Panel Results.

	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.029***	0.030***	0.029***	0.029***	0.030***	0.023***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Wave 2		-0.063***	-0.062***	0.042	-0.063***	-0.043***
		(0.009)	(0.009)	(0.050)	(0.009)	(0.008)
Wave 4		-0.007	-0.003	0.148***	-0.007	0.042***
		(0.012)	(0.012)	(0.049)	(0.012)	(0.008)
Wave 5		-0.063***	-0.057***	0.034	-0.063***	
		(0.014)	(0.014)	(0.051)	(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***	-3.909***	-3.914***	-3.967***	-3.909***	-3.473***
	(0.064)	(0.069)	(0.076)	(0.080)	(0.069)	(0.076)
Observations	17,596	17,596	17,596	17,596	17,596	17,596
R^2	0.119	0.121	0.176	0.177	0.122	0.061
Country	All	All	All	All	All	All
Dummy Var./other	-	Wave	Wave + country	Countrywave + wave	Wave (plus RE)	FE + wave
Gender	female	female	female	female	female	female
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.

The results summarized in Tables 4 and 5 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

Table 5: Men Aged 90 or Younger. Panel Results.

	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.026***	0.025***	0.024***	0.024***	0.025***	0.026***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Wave 2		-0.036***	-0.033***	-0.013	-0.036***	-0.038***
		(0.013)	(0.013)	(0.070)	(0.013)	(0.010)
Wave 4		0.066***	0.073***	0.119*	0.066***	0.063***
		(0.016)	(0.016)	(0.070)	(0.016)	(0.010)
Wave 5		0.004	0.013	0.003	0.004	
		(0.019)	(0.019)	(0.072)	(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***	-4.101***	-3.958***	-4.054***	-4.101***	-4.132***
	(0.082)	(0.090)	(0.100)	(0.108)	(0.090)	(0.107)
Observations	13,292	13,292	13,292	13,292	13,292	13,292
R^2	0.0758	0.078	0.109	0.111	0.0778	0.056
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.

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. (2002). 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.

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 waves, we performed the variable addition tests, 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 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 14 and 15). Then we also included an interaction between the age variable and the extra variable and in none of the cases was this interaction significant. This two exercises suggest that our results are not biased due to the consideration of only the people alive.

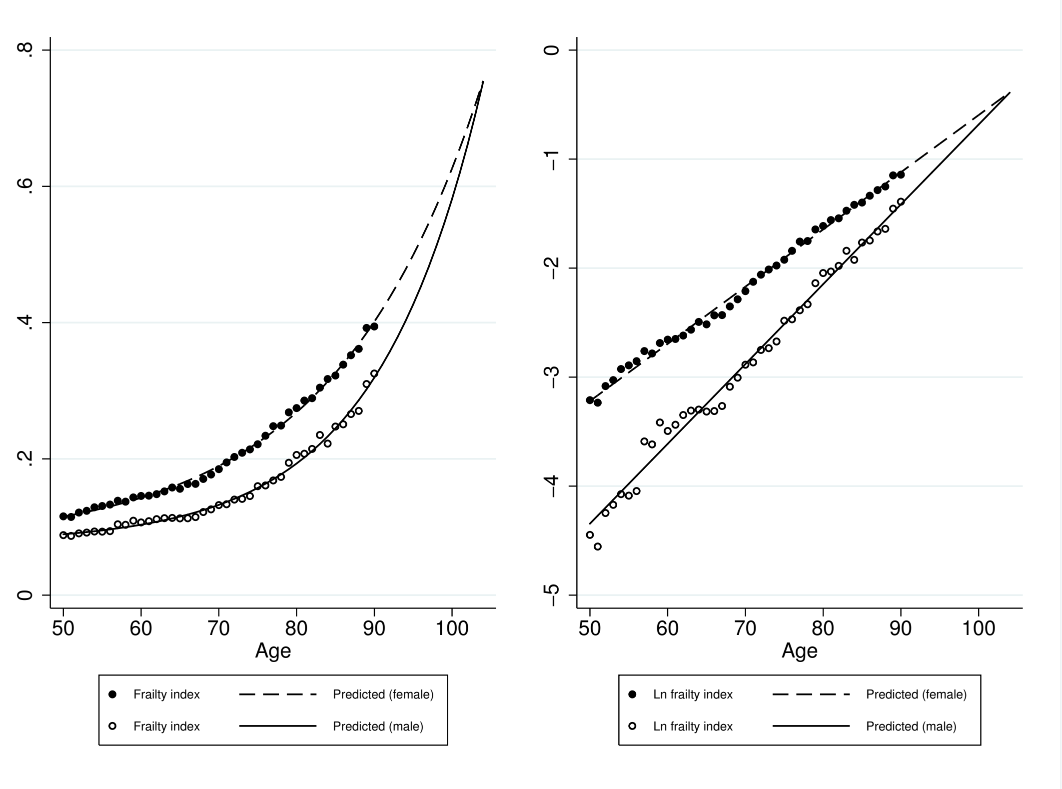
2.3. **Non-Linear Estimation Results.** We next abandon the log-linear specification and estimate an exponential relationship of the Gompertz-Makeham structure. This approach is inspired by Mitnitski et al. (2002) who argued in favor of such a specification based on the conceptual similarity of aging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

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

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". 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 5. 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 3 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 6.3)).

Table 5: Non-linear least squares, by wave.

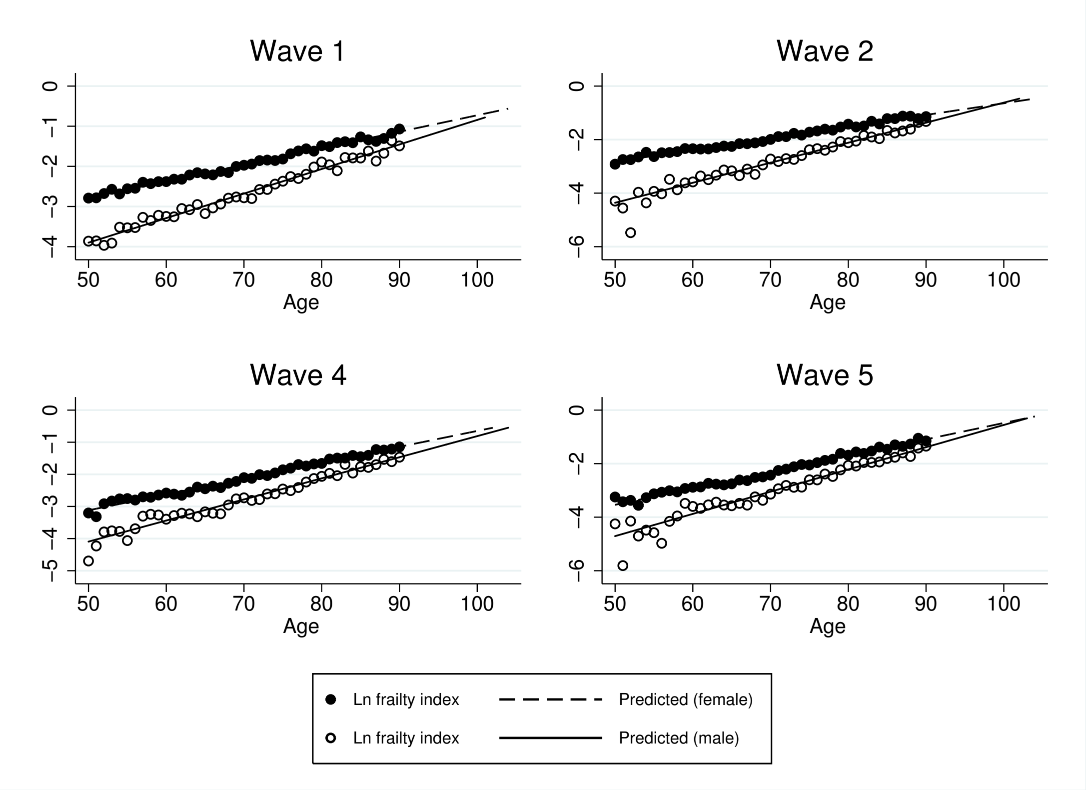
	(1)	(2)	(3)	(4)	(5)
A_f	0.0754***	0.0542***	0.0491***	0.0773***	0.0833***
	(0.0049)	(0.0168)	(0.0170)	(0.0090)	(0.0088)
R_f	0.0029***	0.0080**	0.0067**	0.0037***	0.0014**
	(0.0005)	(0.0035)	(0.0031)	(0.0012)	(0.0006)
α_f	0.0525***	0.0411***	0.0436***	0.0494***	0.0611***
	(0.0019)	(0.0045)	(0.0047)	(0.0032)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

In Table 5 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 of 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^2s above 98 percent.

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, Section 6.3) 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 6 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

Figure 2: Adjusted Health Deficits and Age by Wave



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 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 France and for women in Spain. Figure 3 shows the adjusted health deficit index by age for all countries. We see that everywhere initially unhealthier women (black dots) age more slowly than men (white dots) such that the age trajectories intersect at some high age around 100.

In 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.

3. The Compensation Effect of Deficit Accumulation

As shown in Tables 5 and 6 and Figures 1-3 (and previously for Canadians by Mitnitski et al., 2002), 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.

Table 6: Non-linear least squares, by country.

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

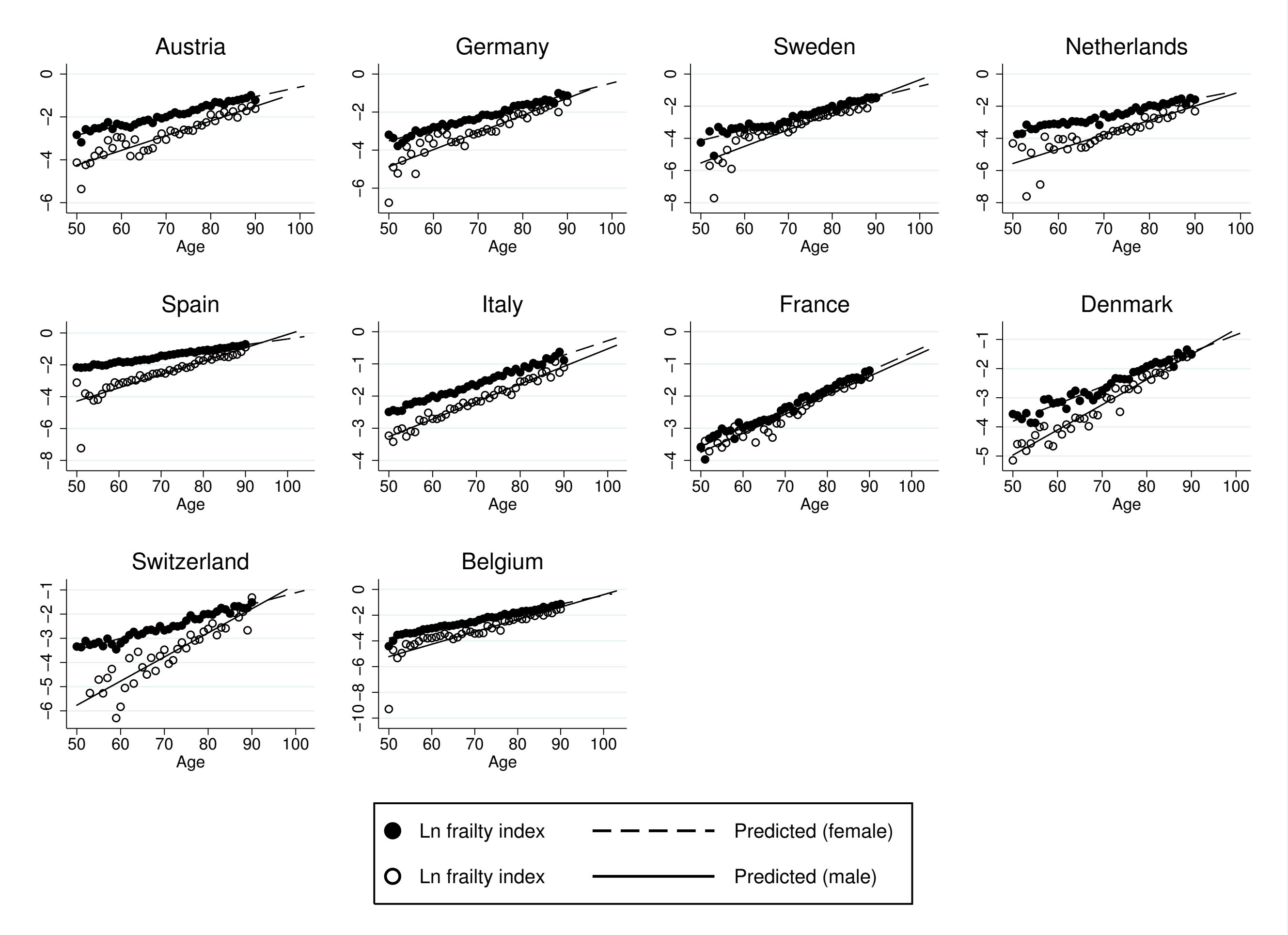
Likewise, countries, where men or women start out initially healthier (lower R) display higher rates of health deficit accumulation (higher α), see Tables 5 and 6. As shown in Figures 2 and 3, the strong negative relationship between α and $\ln(R)$ appears to be close to linear across waves in the Share samples as well as across countries for men and women.

Table 7: Compensation Effect Regression.

	(1) men	(2) women
B	-103.0***	-102.737***
	(8.450)	(4.349)
β	-0.540	-0.473
	(0.476)	(.367)
Unit of observation	countries	countries
Observations	10	10
R^2	0.949	0.986

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

Figure 3: Compensation law of deficit accumulation by country



Gavrilova, 1991), and following Mitnitski et al. (2002), we regress α on the $\ln(R)$, separately for men and women, across countries (using the pooled data):

$$\alpha_{gw} = \beta_g + B_g \log(R_{gw}) \tag{3}$$

in which w represents the waves (replaced by c for the country-level regressions) and g indicates the gender as before. The results are shown in Table 7. Interestingly, the point estimate of B is about the same, around 103, for men and women while the estimate of β is somewhat higher (less negative) for men than for women.

The implications of these results can best be seen by inserting Equation (3) in Equation 2. Leaving aside the country or wave subscripts and using the transformation $\bar{D}_g = \log(\beta_g)$ this provides

$$D_{ig} - A_g = \bar{D}_g \mathrm{e}^{\alpha_{ig}(age_{ig} - B_g)}. \tag{4}$$

Figure 4: Compensation Effect for Wave Estimates

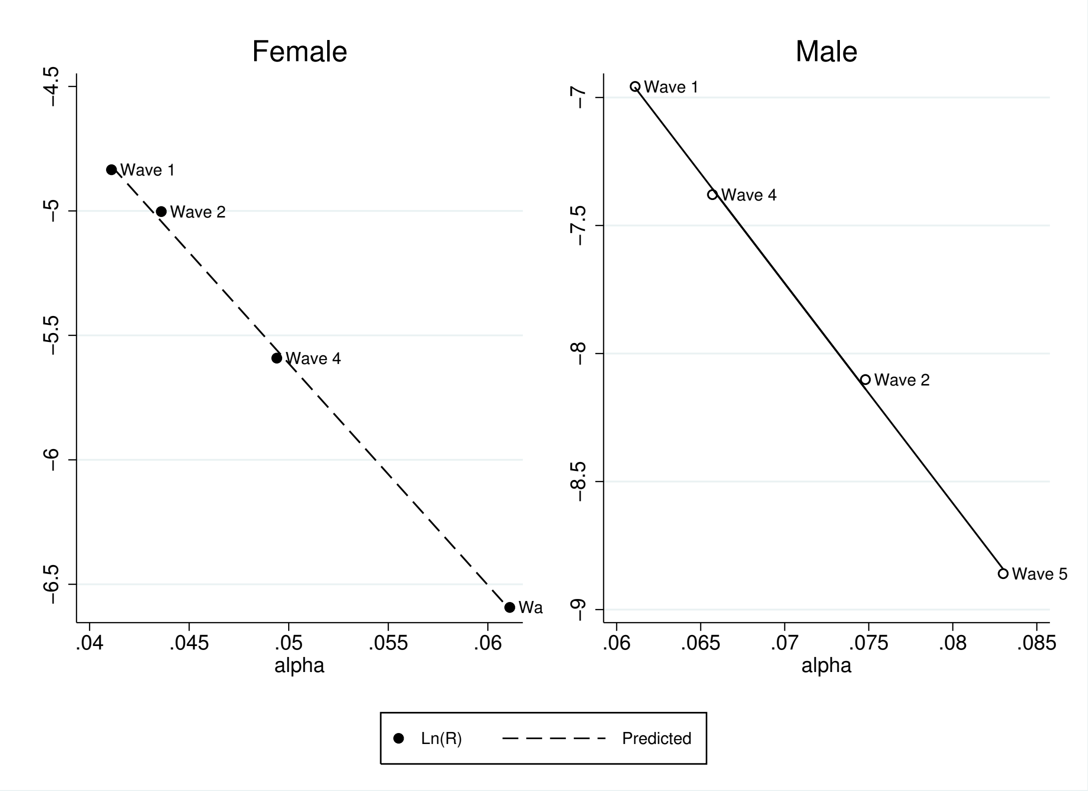
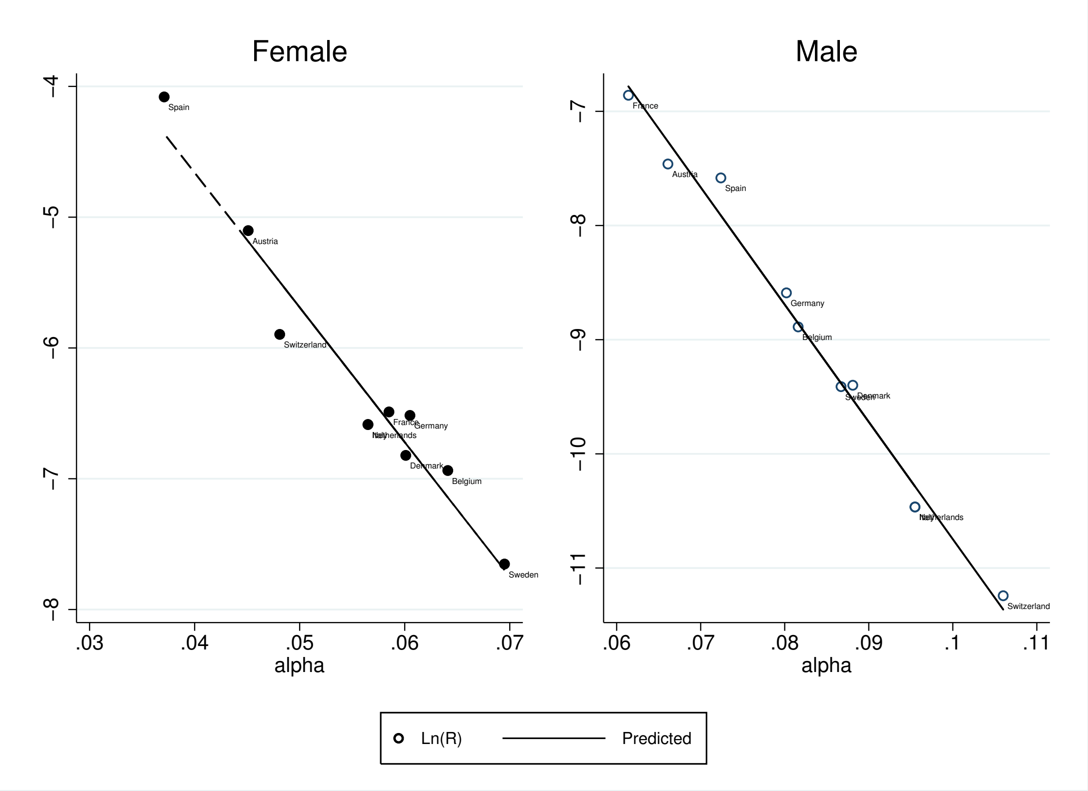


Figure 5: Compensation Effect for Country Estimates



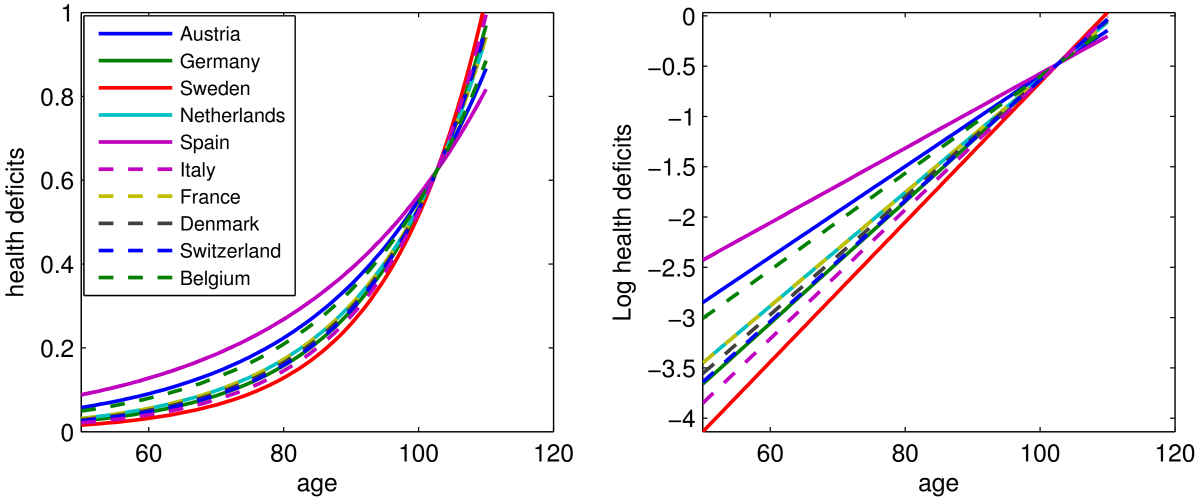
On the left hand side of equation (4) we have the age-dependent part of the health deficit index (D_{ig} corrected by the age-independent Makeham term A_g). Equation (4) suggests that there exists a common age, namely B_g at which age-dependent health deficits for gender g are the same, namely $\bar{D}_g$, across the European countries. Moreover, as seen from Table 7, the age at which health deficits coincide is about the same for men and women, namely about 103 years. The health deficits $\bar{D}_g$, accumulated at this age, however, differ somewhat between men and women. They are given by the point estimates of B as $\exp(-0.47) = 0.630$ for men and $\exp(-0.54) = 0.583$ for women. Because we have only 10 data points, the point estimates are statistically not identified to be different from zero. The overall precision of the estimates, however, is quite high, as indicated by the R^2s above 94 percent.

Interestingly, our estimates of $\bar{D}_g$ 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 5 (of about 0.075) to the $\bar{D}_g$'s to obtain 0.705 for men and 0.658 for women. The previous studies had suggested that there exists an upper (attainable) limit of the health deficit index of 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 (4) the country- (and gender-) specific estimates of α from Table 7. The results are shown in Figures 6 and 7. Along the ordinate we measure age-dependent health deficits ($D_g - A_g$), on the right hand side we log-scale this variable, for better visibility. In Figure 6 we see that Spanish men are the less healthiest in our European sample, next to the Austrians and Belgians, while Swedish men are the healthiest, next to Italian, Swiss and German men. Initially healthier men are aging faster subsequently in a way such that all trajectories intersect at a common age of 103.

Structurally, we observe the same picture for women albeit with a somewhat different country ranking. Among women, the Danish are the less healthiest. This perhaps surprising result is in line with previous research on exceptional mortality of Danish women (e.g. Jacobsen et al., 2004). Next to the Danish are the Austrians and Spanish women while Belgian women are the healthiest next to the Dutch and French. As for men, women in initially healthier countries

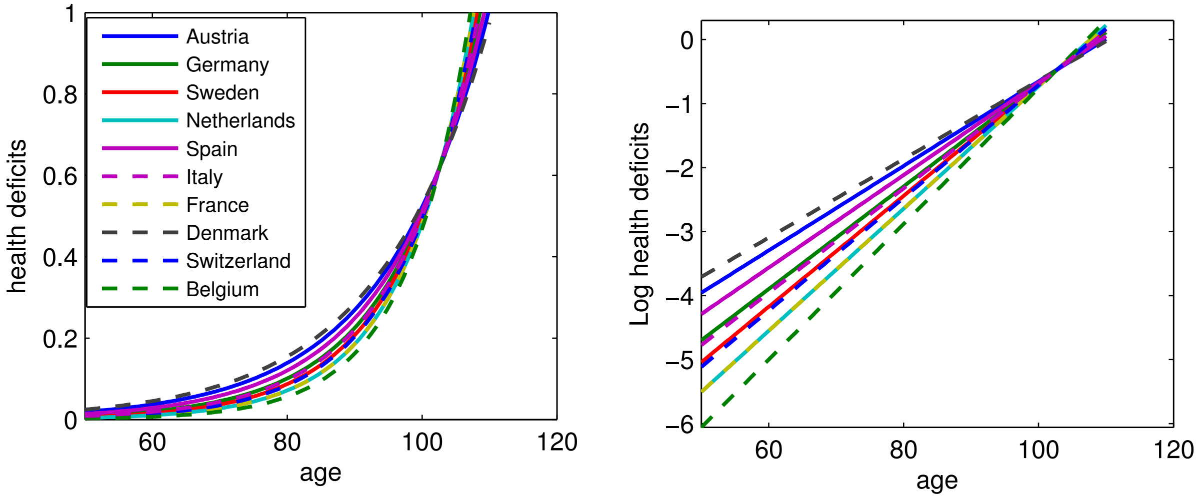
FIGURE 6: AGING IN EUROPE: MEN



The figure shows age-dependent health deficits $(D_g - A_g)$ across countries, according to equation (4) when the country-specific force of aging α_{if} is fed in from the estimates of Table 7.

accumulate additional health deficits faster such that a common intersection at an age of about 103 emerges.

FIGURE 7: AGING IN EUROPE: WOMEN



The figure shows age-dependent health deficits $(D_g - A_g)$ across countries, according to equation (4) when the country-specific force of aging α_{im} is fed in from the estimates of Table 7.

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 103 where individuals, on average, age in the same way across gender and across countries.

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 some 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, in principle, be smoothed out be 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.

4.1. **Acknowledgements.** We would like to thank Kenneth Harttgen, Sebastian Vollmer, and Arnold Mitnitski for helpful comments. This paper uses data from SHARE Waves 1, 2, 4, and 5 (DOIs: 10.6103/SHARE.w1.500, 10.6103/SHARE.w2.500, 10.6103/SHARE.w4.500, 10.6103 /SHARE.w5.500), see Börsch-Supan et al. (2013) for methodological details. The SHARE data collection has been primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812) and FP7 (SHARE-PREP: N.211909, SHARE-LEAP: N.

227822, SHARE M4: N.261982). Additional funding from the German Ministry of Education and Research, the U.S. National Institute on Aging (U01-AG09740-13S2, P01-AG005842, P01-AG08291, P30-AG12815, R21-AG025169, Y1-AG-4553-01, IAG-BSR06-11, OGHA-04-064) and from various national funding sources is gratefully acknowledged (see `www.share-project.org`).

5. References

Arking, R., 2006, *The Biology of Aging: Observations and Principles*, Oxford University Press, Oxford.

Barlow, R.E. and Proschan, F. (1975). *Statistical theory of reliability and life testing: Probability models*, Holt, Rinehart and Winston, New York.

Bennett, S., Song, X., Mitnitski, A., and Rockwood, K. (2013). A limit to frailty in very old, community-dwelling people: a secondary analysis of the Chinese longitudinal health and longevity study. *Age and Ageing* 42(3), 372-377.

Breusch, T. S. and A. R. Pagan. 1980. The Lagrange multiplier test and its applications to model specification in econometrics. *Review of Economic Studies*, 47, 239–253.

Carey, J.R. (2003) Life span: a conceptual overview. *Population and Development Review* 29,1-18.

Carnes, B.A. and Olshansky, S.J. (2007). A realist view of aging, mortality, and future longevity, *Population and Development Review* 33, 367- 381.

Contoyannis, P., Jones, A. M., and Rice, N. (2004). The dynamics of health in the British Household Panel Survey, *Journal of Applied Econometrics* 19(4), 473-503.

Finkelstein, M.S. (2008). *Failure Rate Modeling for Risk and Reliability*, Springer, London.

Finch, C.E. and Pike, M.C. (1996). Maximum life span predictions from the Gompertz mortality model. *Journal of Gerontology* 51, 183–194.

Fries, J.F. (1980). Aging, natural death, and the compression of morbidity. *New England Journal of Medicine* 303, 130-135.

Gavrilov, L.A. and Gavrilova, N.S. (1991). *The Biology of Human Life Span: A Quantitative Approach*, Harwood Academic Publishers, London.

Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society of London* 115, 513–583.

Grossman, M. (1972). On the concept of health capital and the demand for health. *Journal of Political Economy* 80, 223-255.

Harttgen, K., Kowal, P., Strulik, H., Chatterji, S., Vollmer, S. (2013). Patterns of frailty in older adults: comparing results from higher and lower income countries using the Survey of Health, Ageing and Retirement in Europe (SHARE) and the Study on Global AGEing and Adult Health (SAGE). *PLOS One* 8(10), e75847.

Jacobsen, R., Osler, M., Lynge, E., and Keiding, N. (2004). Women's death in Scandinavia: what makes Denmark different? *European Journal of Epidemiology* 19(2), 117-121.

Kulminski, A., Yashin, A., Ukraintseva, S., Akushevich, I., Arbeev, K., Land, K., and K. Manton (2006). Accumulation of health disorders as a systemic measure of aging: Findings from the NLTCS data. *Mechanisms of ageing and development* 127(11), 840–848.

Makeham, W.M. (1860). On the law of mortality and the construction of annuity tables, *Journal of the Institute of Actuaries* 8, 301–310.

Masoro, E.J. (2006) Are age-associated diseases and integral part of aging? in: Masoro, E.J. and Austad, S.N., (eds.), *Handbook of the Biology of Aging*, Academic Press.

Mitnitski, A.B., Mogilner, A.J., and Rockwood, K. (2001). Accumulation of deficits as a proxy measure of aging. *Scientific World* 1, 323-336.

Mitnitski, A.B., Mogilner, A.J., MacKnight, C., and Rockwood, K. (2002). The accumulation of deficits with age and possible invariants of aging. *Scientific World* 2, 1816-1822.

Mitnitski, A.B. and Mogilner, A.J. and MacKnight, C. and Rockwood, K. (2002b). The mortality rate as a function of accumulated deficits in a frailty index. *Mechanisms of Ageing and Development* 123, 1457-1460.

Mitnitski, A., and K. Rockwood. (2016). The rate of aging: the rate of deficit accumulation does not change over the adult life span. *Biogerontology*, 17(1), 199–204.

Mitnitski, A. and Song, X. and Skoog, I. and Broe, GA and Cox, J.L. and Grunfeld, E. and Rockwood, K., 2005. Relative fitness and frailty of elderly men and women in developed countries and their relationship with mortality. *Journal of the American Geriatrics Society* 53, 2184–2189.

Novoseltsev, V.N. (2006). Mathematical modeling in biology: Systems capable to live and die. *Automation and Remote Control* 67, 835–855.

Oeppen, J. and Vaupel, J.W. (2002). Broken limits to life expectancy. *Science* 296, 1029–1031.

Olshansky, S.J. and Carnes, B.A. (1997). Ever since Gompertz. *Demography* 34, 1-15.

Rockwood, K. and Mitnitski, A. (2006). Limits to deficit accumulation in elderly people. Mechanisms of ageing and development, 127(5), 494-496.

Rockwood, K. and Mitnitski, A.B., 2007. Frailty in relation to the accumulation of deficits. *Journals of Gerontology Series A: Biological and Medical Sciences* 62, 722–727.

Romero-Ortuno, R., and Kenny, R.A. (2012). The frailty index in Europeans: association with age and mortality. *Age and Ageing* 41(5), 684-689.

Romero-Ortuno, R. (2014). Frailty Index in Europeans: association with determinants of health. *Geriatrics & Gerontology International* 14(2), 420-429.

Strehler, B.L. and Mildvan, A.S. (1960). General theory of mortality and aging, *Science* 132, 14-21.

Strulik, H., Vollmer, S. (2013). Long-run trends of human aging and longevity. *Journal of Population Economics* 26(4), 1303-1323.

Theou, O., Brothers, T. D., Mitnitski, A., and Rockwood, K. (2013). Operationalization of Frailty Using Eight Commonly Used Scales and Comparison of Their Ability to Predict All-Cause Mortality. *Journal of the American Geriatrics Society* 61(9), 1537-1551.

Verbeek, M., and Nijman, T. (1992). Testing for selectivity bias in panel data models. *International Economic Review* 33, 681-703.

Wilmoth, J.R. and Robine, J.M. (2003). The world trend in maximum life span. *Population and Development Review* 29, 239-257.

Yashin, A.I., Begun, A.S., Boiko, S.I., Ukraintseva, S. V., and Oeppen, J. (2001). The new trends in survival improvement require a revision of traditional gerontological concepts. Experimental Gerontology, 37(1), 157-167.

Zheng, H., Yang, Y., and Land, K.C. (2011). Heterogeneity in the Strehler-Mildvan general theory of mortality and aging. Demography, 48(1), 267-290.

Zheng, H. (2014). Aging in the context of cohort evolution and mortality selection. Demography, 51(4), 1295-1317.

6. APPENDIX

6.1. **Definition of variables.**

TABLE 8: 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 kneeing	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 9: Panel analysis sample, by wave.

	All			**Females**			**Males**		
Wave	**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 10: Panel analysis sample, by country.

	All			**Females**			**Males**		
Country	**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 11: All sample, by wave.

	All			**Females**			**Males**		
Wave	**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 12: All sample, by country.

	All			**Females**			**Males**		
Country	**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 13: All sample, by broad age group.

	All			**Females**			**Males**		
Age group	**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

Selection tests

Table 14: Variable addition tests (Females).

	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.029***	0.030***	0.029***	0.029***	0.040***	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.007)	
Wave sum	-0.178***	-0.170***	-0.163***	-0.163***	-0.004	
	(0.014)	(0.015)	(0.014)	(0.014)	(0.110)	
Age	0.029***	0.030***	0.029***	0.029***	0.030***	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	
Balanced	-0.435***	-0.419***	-0.404***	-0.404***	-0.413***	
	(0.035)	(0.037)	(0.036)	(0.036)	(0.036)	
Age	0.030***	0.031***	0.030***	0.030***	0.033***	0.023***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Next wave	-0.495***	-0.521***	-0.505***	-0.505***	-0.314***	-0.201***
	(0.051)	(0.052)	(0.050)	(0.050)	(0.036)	(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 15: Variable addition tests (Males).

	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.026***	0.025***	0.025***	0.025***	0.025***	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	
Wave sum	-0.244***	-0.255***	-0.254***	-0.254***	-0.242***	
	(0.015)	(0.016)	(0.015)	(0.015)	(0.015)	
Age	0.026***	0.025***	0.024***	0.024***	0.025***	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	
Balanced	-0.607***	-0.637***	-0.631***	-0.631***	-0.632***	
	(0.036)	(0.038)	(0.037)	(0.037)	(0.037)	
Age	0.027***	0.028***	0.027***	0.027***	0.032***	0.026***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Next wave	-0.704***	-0.760***	-0.747***	-0.746***	-0.464***	-0.261***
	(0.053)	(0.054)	(0.053)	(0.053)	(0.043)	(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.

6.3. **Robustness - results using 85 years cutoff.**

Table 16: Panels results, female balanced sample, up to 85 years of age.

	(1)	(2)	(3)	(4)	(5)
Age	0.030***	0.029***	0.029***	0.030***	0.022***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Wave 2	-0.063***	-0.060***	0.047	-0.063***	-0.039***
	(0.010)	(0.010)	(0.052)	(0.010)	(0.008)
Wave 4	-0.008	-0.002	0.155***	-0.008	0.047***
	(0.013)	(0.013)	(0.051)	(0.013)	(0.008)
Wave 5	-0.071***	-0.063***	0.023	-0.071***	
	(0.016)	(0.015)	(0.053)	(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)			
23.country		0.053			
		(0.041)			
Constant	-3.891***	-3.872***	-3.927***	-3.891***	-3.403***
	(0.080)	(0.086)	(0.091)	(0.080)	(0.077)
Observations	16,508	16,508	16,508	16,508	16,508
R-squared	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 17: Panels results, male balanced sample, up to 85 years of age.

	(1)	(2)	(3)	(4)	(5)
Age	0.024***	0.022***	0.022***	0.024***	0.024***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Wave 2	-0.040***	-0.036***	-0.033	-0.040***	-0.041***
	(0.013)	(0.013)	(0.072)	(0.013)	(0.011)
Wave 4	0.069***	0.080***	0.109	0.069***	0.069***
	(0.017)	(0.017)	(0.072)	(0.017)	(0.011)
Wave 5	0.001	0.015	-0.011	0.001	
	(0.020)	(0.020)	(0.075)	(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***	-3.799***	-3.883***	-3.984***	-3.993***
	(0.100)	(0.110)	(0.117)	(0.100)	(0.108)
Observations	12,680	12,680	12,680	12,680	12,680
R-squared	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 8: Non-linear least squares, all sample restricted to 85

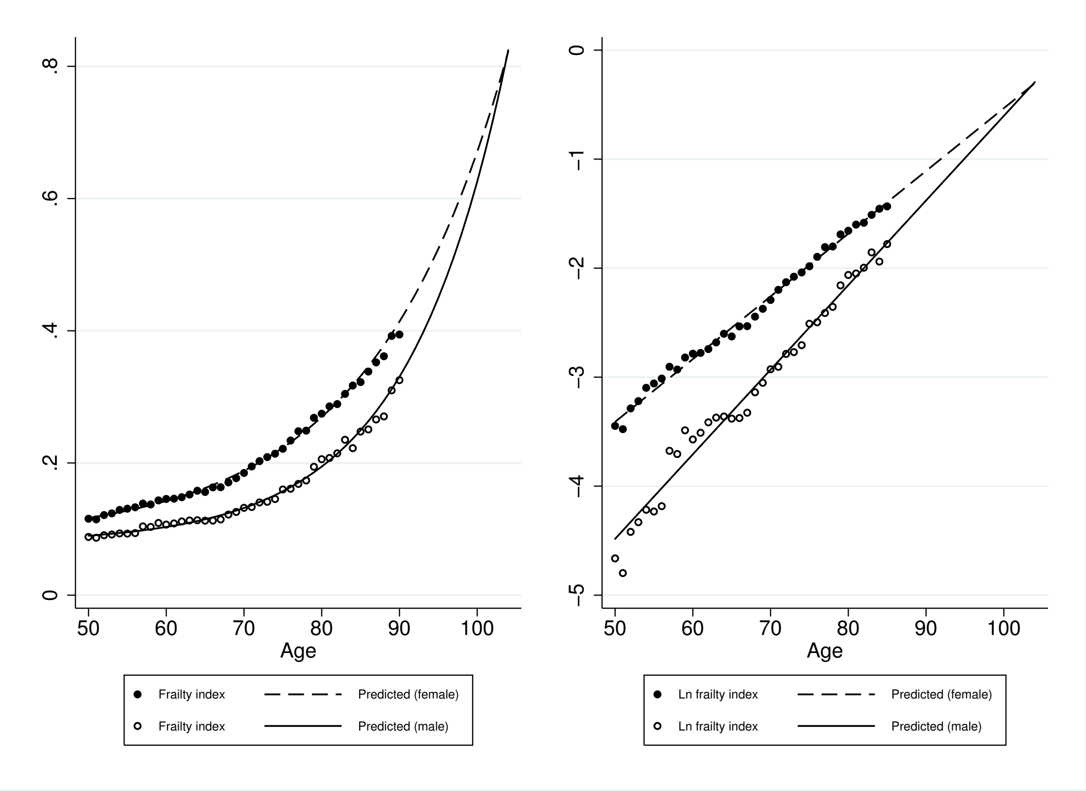


Figure 9: Ordinary least squares by wave, 85 years cutoff

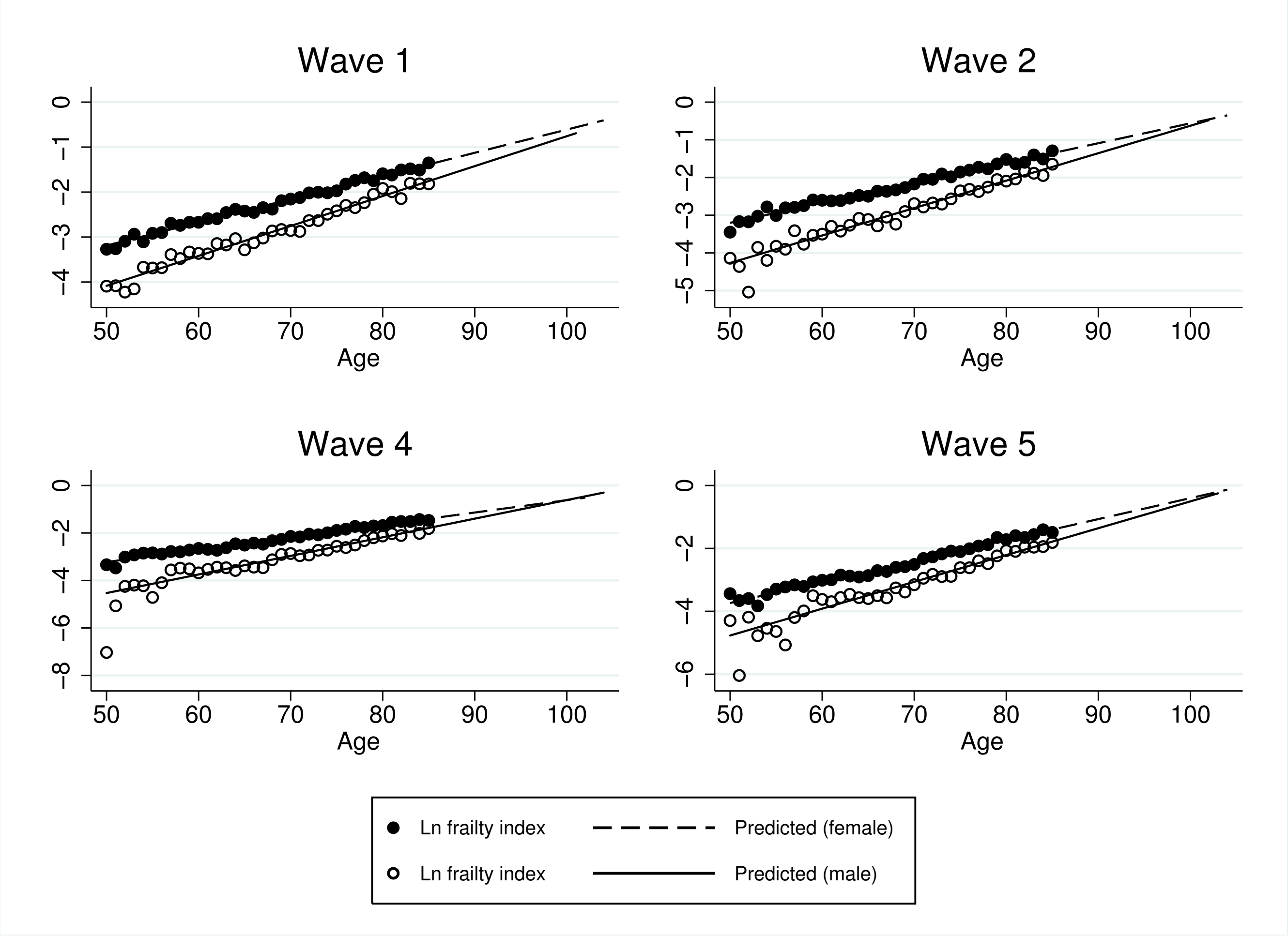


Figure 10: Ordinary least squares by country, 85 years cutoff