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Immigrant-native health disparities: a test of the weathering hypothesis

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Health disparities between immigrants and non-immigrants: a test of the weathering hypothesis

Abstract

The weathering hypothesis implies that there is an interaction between age and race or ethnicity that results in disadvantaged groups experiencing a more rapid decline in health than other groups. The weathering hypothesis has been tested based on racial or ethnic identity, less is known about weathering by immigration status. We address three research questions: Are immigrants, and especially immigrant women, ageing in poorer health? Does education protect immigrants from a faster health decline with age? How do income and marital status affect the health trajectories of immigrants and non-immigrants? We focus on Germany and estimate trajectories of declining health and ages at crossover between immigrants and non-immigrants. We find that immigrants, and especially immigrant women, age in poorer health than non-immigrants. We show that high education explains the differential relationship between age, immigrant status, and health. Differences persist after employment and marital status are considered.

Keywords: Weathering hypothesis; ageing; health trajectories; immigrant health

Introduction

Immigration and population ageing are among the major forces shaping the size and the composition of the European population. The growing and stable presence of immigrant populations has led to an increased interest in the integration of immigrants, including in immigrant health, among scholars and policymakers. There is extensive recognition that research on immigrant health is essential to help reduce inequalities in health in general (Nielsen & Krasnik 2010; Wilkinson & Marmot 2003).

Despite having better health upon arrival, the health of immigrants declines more rapidly than the health of non-immigrants as they age (Gubernskaya 2014; Loi et al 2022; Ronellenfitsch & Razum 2004). The initial, paradoxical gap – known as the healthy immigrant effect (Abraído-Lanza et al 1999) – is caused by the health selectivity of individuals who successfully migrate to the receiving countries, and by immigrants' better health behaviours (Abraído-Lanza et al 1999; Lechner & Mielck 1998; Loi & Hale 2019; Palloni & Arias 2004; Ronellenfitsch & Razum 2004). The health selection of immigrants is particularly strong upon arrival, and in the years immediately thereafter. However, the health advantage of immigrants tends to diminish relatively quickly with the length of stay – i.e., around 10 years after arrival, most health differences between immigrants and non-immigrants have disappeared (Loi & Hale 2019) – and as immigrants age in the receiving societies (Kristiansen et al 2016). It therefore appears that immigrants are at greater risk than non-immigrants of ageing in poorer health.

Previous research has indicated that compared to non-immigrants, older immigrants have lower life expectancy, decreased physical functioning, higher rates of depression, and poorer self-rated health (Aichberger et al 2010; Lanari & Bussini 2012; Reus-Pons et al 2018). However, the majority of these studies failed to take into account trajectories over age, or the differences in

these trajectories by sex, socio-economic status, and their interactions with age. While individual and population health risks arise from multiple sources across the life course, most research designs still tend to focus on the effects on health outcomes of single exposures, or on the additive role of different exposures. In order to understand the mechanisms that explain why immigrants age in poorer health than non-immigrants, we need to use approaches that consider the complexity of the social world. Unitary approaches are very limited, as they assume that individual characteristics operate in an additive manner, and are layered on top of one another (Bauer 2014).

We address these limitations in the literature, and seek to explain how structural factors, both separately and combined, produce and exacerbate health inequalities between immigrants and non-immigrants with age.

Theoretical background

Persistent exposure to socio-economic disadvantage has been linked to more rapid health decline, and helps to explain ethnic and racial disparities on a range of health outcomes (Forde et al 2019). This process is often referred to in the literature as weathering (Geronimus 1992, 1996). The process of weathering leads to accelerated aging and to the early onset of chronic diseases and excess mortality among marginalized groups (Jones et al 2019). As such, the process of "weathering" can be interpreted as a physical consequence of social inequality (Geronimus 1996).

The weathering hypothesis was first introduced to study Black/White differences in the relationship between maternal age and birth weight and other perinatal health outcomes (Geronimus 1992, 1996). Research that examined levels of neonatal mortality and of low birth weight among first births found that the age-specific distributions differ between Black and White

women. In particular, it was shown that the health of Black women begins to deteriorate earlier in adulthood as a physical consequence of cumulative socio-economic disadvantages, whereas the health of White women starts to deteriorate at older ages (Geronimus 1992; Wildsmith 2002). This differential pattern of deterioration between Black and White women has an impact on the health of their new-borns. Although research on the weathering hypothesis has primarily focused on racial and ethnic differences in perinatal health outcomes, this theoretical framework can be used more generally to help explain the adverse effects of cumulative disadvantage over the life course among any minority group, including among immigrants (Wildsmith 2002).

The evidence of the weathering process provides us with a fundamental insight: age is not only a biological developmental indicator, but it is also a reflection of the ways in which social inequality, discrimination, or bias in exposures to psychosocial or environmental hazards can lead to health differences between groups, including between immigrants and non-immigrants (Geronimus 1992; Wildsmith 2002). While there is a large body of literature on differential ageing by race and ethnicity, fewer studies have examined patterns of weathering by immigration status (Wildsmith 2002), especially in the European context. There is, however, evidence in the literature on migration and health that age does not relate to health in the same way among immigrants as it does among non-immigrants. Due to the healthy immigrant effect (Abraído-Lanza et al 1999; Markides & Coreil 1986; Moullan & Jusot 2014), immigrants have better health than non-immigrants at younger ages. But with increasing age, the health of immigrants deteriorates faster than the health of non-immigrants, which results in immigrants having poorer health than non-immigrants at older ages (Gubernskaya 2014; Kristiansen et al 2016).

Inequalities in health status appear to be related to exclusion and inequalities in socio-economic status (Kosteniuk & Dickinson 2003; Lahelma et al 2004; Mackenbach et al 2015;

Marmot et al 2012). Common indicators of socio-economic status are education and income. Education impacts health indirectly by encouraging healthy behaviours, and directly by enabling access to medical care (Lahelma et al 2004; Leigh 1983; Mackenbach et al 2015). Moreover, having more education provides individuals with a cultural supply that raises their awareness about their own health conditions and health prevention (Ross & Chia-Ling Wu 1995). It is, however, known that the distribution of education between immigrants and non-immigrants is unequal, and that the economic returns to education are lower for immigrants than for non-immigrants. While previous studies have shown that among immigrants, education is related to health in the form of a “flat gradient”, interpretations of this evidence have been mixed (Acevedo-Garcia et al 2007; Balistreri & Van Hook 2009; Riosmena & Dennis 2012). Several potential mechanisms that may explain the flat social gradient in health among immigrants have been proposed: factors related to conditions in the country of origin, or "gradient importation"; factors related to emigration and return migration, or "SES-graded health selection"; and acculturation and protection mechanisms in the receiving countries, or "SES-graded acculturation" (Riosmena & Dennis 2012, p. 97). To extend our knowledge on these relationships, it is essential that we study the role of education in the health trajectories of immigrants. In addition to education, it is important to consider income, as income has a direct impact on individuals’ access to the material resources they need for their biological survival, and influences their social involvement and environment, which, in turn, shape the conditions that support good health (Marmot 2002).

Aims and research questions

The first aim of this paper is to describe how the health trajectories of immigrants and non-immigrants differ with age. Our first research question is as follows: (*RQ 1*) Compared to non-

immigrants, are immigrants ageing in poorer self-perceived health, and with a higher probability of having a physical limitation? The second aim is to test whether education plays a protecting role in the development of the health gap between immigrants and non-immigrants with age. We ask the following question: (*RQ 2*) Does education play a role in mitigating the differential health trajectories of immigrants and non-immigrants as they age? Is high education associated with a narrowing of the health gap between immigrants and non-immigrants? The third aim is to consider two additional layers of socio-economic disadvantage: income and marital status. We include income in our analysis in order to test whether the immigrant health disadvantage by education persists or is reduced when immigrants and non-immigrants have equal income levels. Testing this association also sheds light on the question of whether the unclear association between health and education observed among immigrants (Acevedo-Garcia et al 2007; Balistreri & Van Hook 2009) can be explained by immigrants having lower economic returns to education. We include in our analysis marital status, as marriage is a strong protective factor for health (Dupre et al 2009; Rendall et al 2011). However, the marriage patterns of immigrants are very different from those of non-immigrants (Andersson et al 2015). We therefore ask the following question: (*RQ 3*) Does being married and having a high socio-economic status protect immigrants from experiencing a more rapid health decline? The fourth aim is to examine whether there are sex differences in the abovementioned mechanisms. Thus, we ask the following question: (*RQ 4*) Is the hypothesised differential health decline between immigrants and non-immigrants especially pronounced among women? Finally, as a sensitivity check, we test whether the relationship between age and health depends not only on immigration status, but also on the specific country of birth (results available in the online supplementary material).

Methods

Data

In our analysis, we use data from a nationally representative longitudinal study of private households, the German Socio-Economic Panel (G-SOEP). The G-SOEP is a representative longitudinal study of private households with the data providing information on all household members, including of Germans living in former West and East Germany, foreigners, and recent immigrants to Germany. Topics covered by the survey include household composition, occupational biographies, employment, earnings, health and satisfaction indicators. We use waves 1994-2019 to study self-rated health and waves 2002-2019 to study disability. We focus on the population aged 30-80 years. We exclude from our sample individuals with the following characteristics: individuals who were under age 18 at immigration, or second-generation immigrants, in order to avoid heterogeneity in health selectivity by generation that could bias our results; individuals who migrated to Germany less than 10 years prior to entering the study in order to avoid health selectivity of recently arrived immigrants due to the healthy immigrant effect; individuals with missing information on the two outcomes, self-rated health and disability, and on the covariates of interest, education, marital status, and income. The final sample used to study self-rated health consisted of 57,401 individuals: 6259 immigrants (3026 men and 3233 women) and 51,142 non-immigrants (24,739 men and 26,403 women). The sample used for studying disability consisted of 41,934 individuals: 4468 immigrants (2070 men and 2398 women) and 37,466 non-immigrants (17,809 men and 19,657 women).

Outcome measures

It is crucial to consider the suitability of the health indicators used when comparing groups or societies with different cultures and different disease distributions (Braveman et al 2010; Burgard & Chen 2014). To limit problems of comparability, we include two indicators of morbidity that define different dimensions of health: self-rated health and disability. Self-rated health is measured on a scale from one to five (very good, good, fair, bad, very bad), and we recode it such that the highest value indicates worse health. Disability is calculated using the following items of the ADL scale: having trouble getting out of bed, having trouble shopping, having trouble doing housework (all collected every year since 1985), having trouble dressing (collected every year since 1991), and having trouble climbing stairs (collected every two years since 2002). The outcome variable takes the value of one if the individual has one or more limitations in the abovementioned dimensions, and takes the value of zero if the individual has no limitations. For both outcomes, we interpret the results in the same direction: i.e., the higher the value, the worse the health outcome.

Main exposures and covariates

Our main exposure of interest is the interaction between age and immigration status. Immigration status is a binary variable that takes the value 0 for non-immigrants and the value 1 for immigrants. Non-immigrants are individuals born in Germany. We define an immigrant as an individual who was born outside of Germany, who crossed an international border for any reason, and who is a permanent regular resident in Germany. In order to consider the heterogeneity in the immigrant population, we include supplementary analyses that consider the main countries of birth of the immigrant population in Germany. The age of the individuals included in our analysis ranges from 30 to 80. We model age using a spline function, which relies less on pre-imposed

functional specifications, and allows for more flexibility (de Boor 1980). Education is defined using three categories: less than high school, high school degree, and higher than high school. As we do not have information about the country where the degree was obtained (Germany vs. other countries), we use this broad definition of education in order to limit issues of comparability across different cultures. Still, it is important to point out that levels of education might have slightly different qualitative meanings across different cultures, and that our strategy does not fully prevent a certain amount of bias due to these differences[1].

Method

We describe and explain how the health trajectories of immigrants and non-immigrants differ with age using linear models for self-rated health, and linear probability models for disability. In order to account for the bias due to loss to follow-up, and the potential "salmon bias", we apply inverse probability weighting (IPW) techniques. Individuals are weighted by the inverse of their probability of participating in the study. This probability is related to each individual's characteristics, such as age, education, marital status, and income. The use of IPW implies that an individual with a high probability of response is given a lower weight in the analysis (Metten et al 2022).

First, we test whether the relationship between health and age is different between immigrants and non-immigrants, including an interaction term between age and immigration status

Eq. 1: $$Y = \alpha + \sum_{i=1}^{3} \beta_{1i} age_i + \beta_2 nat + \sum_{i=1}^{3} \beta_{3i} age_i \times nat + \varepsilon$$

[1] We discuss this issue further in the limitations section.

where Y is the health outcome, $\sum_{i=1}^{3}\beta_{1i}age_i$ is the sum of the three age components modelled with a spline function, $\beta_2 nat$ is immigration status, and ε is the error term. We stratify model 1 (Eq. 1) by sex in order to explore sex differences in the health gap between immigrants and non-immigrants with age.

Second, we stratify model 1 (Eq. 1) by educational level and sex in order to test whether the differential weathering process is buffered by education. We test the hypothesis that at higher levels of education, differences in the health trajectories of immigrants and non-immigrants disappear.

Third, we include marital status $marstat$ and income inc and an interaction term between marital status and immigration status, and between income and immigration status (Eq. 2), to account for the differential relationship between these two characteristics and health, depending on whether the individual is an immigrant or a non-immigrants.

Eq. 2:

$$Y = \alpha + \sum_{i=1}^{3}\beta_{1i}age_i + \beta_2 nat + \sum_{i=1}^{3}\beta_{2i}age_i \times nat + \beta_4 marstat + \beta_5 inc + \beta_6 marstat \times nat + \beta_7 inc \times nat + \varepsilon$$

Sensitivity checks

First, we run models without inverse probability weights in order to estimate the magnitude of the bias correction. Second, we run models imputing the outcome missing values due to loss to follow-up. More specifically, we assign the last observed value of self-rated health to individuals who are lost to follow-up. We assign those values at ages 50 to 80, and up to three years after loss to follow-up. The loss to follow-up bias, or "salmon bias", can lead to an

underestimation of poor health. The imputation allows us to expand the observation window to older ages, given that poor health is biased by the loss to follow-up at these ages. Imputing the missing values allows us to show what the health trajectory would look like had these individuals not been lost to follow-up. This approach has one assumption: namely that the health status does not change up to three years after the loss to follow-up. The loss to follow-up in our data is associated with poor health, with individuals in poor health and immigrants more likely to be lost (results not shown). Therefore, individuals who have poor health in the year when they are lost are likely to be in poor health in the following years. This evidence, and limiting the imputation to ages 50+, when health is more likely to start declining, makes us confident that the imputed models are not overestimating poor health. Third, we include marital status and income in separate models to test which factor is most strongly associated with the health gap between immigrants and non-immigrants, as indicated by the following equations:

Eq. 3: $$Y = \alpha + \sum_{i=1}^{3} \beta_{1i} age_i + \beta_2 nat + \sum_{i=1}^{3} \beta_{3i} age_i \times nat + \beta_4 marstat \times nat + \varepsilon$$

Eq. 4: $$Y = \alpha + \sum_{i=1}^{3} \beta_{1i} age_i + \beta_2 nat + \sum_{i=1}^{3} \beta_{3i} age_i \times nat + \beta_4 income \times nat + \varepsilon$$

Fourth, we include country of birth as a stratification factor to test whether the relationship between age and health differs depending on the specific country of birth. Thus, we test model 1 (Eq. 1) stratified by the three largest immigrant groups: born in Turkey, Italy, Poland, or other countries.

Results

We estimate the same set of models for the two outcomes, self-rated health and disability. Table 1 describes the two samples. Immigrants have a younger age structure than non-immigrants and are more likely to be married, which are protective factors for health. However, immigrants of both sexes are overrepresented in the lowest educated and lowest income groups and are underrepresented in the highest education and income groups, which are strong risk factors for poor health. Immigrant women with tertiary education represent an exception, as their share in the high educated group is similar to that of non-immigrant women. The average values of self-rated health are similar for immigrants and non-immigrants and for both men and women, while the proportion of individuals with disabilities is higher among immigrants than among non-immigrants of both sexes.

The weathering process

We present and discuss the results from the models graphically (Figures 1-4), and we include the full estimates of each model in Appendix Tables A1-A4. All models are weighted using inverse probability weighting in order to account for the loss to follow-up, and the so-called "salmon bias" (Abraído-Lanza et al 1999). In Figure 1, we show the self-rated health trajectory by age, immigration status, and sex; and in Figure 2, we show the same trajectory for disability. Solid lines indicate non-immigrants, and dotted lines indicate immigrants. For both outcomes, we observe similar health levels among immigrants and non-immigrants at age 30, and a crossover occurring at ages below 40 across all subgroups (SRH: 36.1 for men and 37.4 for women; disability: 33.8 for women). Disability among men represents an exception to this pattern, as we do not observe crossover: i.e., compared to male non-immigrants, male immigrants do not have a health advantage at younger ages (30 to 45), and have a higher probability of having a disability at ages

50+. After the crossover occurs, the health of immigrants declines faster than that of non-immigrants of both sexes and for both health outcomes. However, we observe trend towards convergence among immigrant and non-immigrants at the oldest ages. An exception to this general convergence trend is found for the probability of having a disability among women, as we still observe significant differences in the probability of having a disability between female immigrants and female non-immigrants at age 80.

The role of education

In Figure 3, we show: 1) the differential self-rated health decline by education (panels A for men and D for women); 2) the same patterns for individuals who are the most advantaged: i.e., who are married and have a high income (panels B for men and E for women); and for individuals who are the most disadvantaged: i.e., who are unmarried and have a low income (panels C for men and F for women). Education is shown by means of different line colors: red for primary education and black for tertiary education (for ease of comparison, we do not plot the results for secondary education, although its effect is estimated in the models, and the results are included in Appendix Tables A1-A4). Although the results come from stratified models, we plot them in the same figure to facilitate the comparison. In Figure 4, we show the same figures for the outcome disability.

We first focus on self-rated health (Figure 3). As expected, when stratifying for education (panels A and D), we observe differences in the overall levels of the self-rated health trajectories: i.e., we find that across the whole age span, self-rated health is poorer among the lowest educated and is better among the highest educated. Most importantly, we find that the health gaps between immigrants and non-immigrants differ between the two education groups. Among

the lowest educated (red lines), we observe wide gaps: in terms of self-rated health, immigrants have an advantage at younger ages and a disadvantage at older ages. Among the highest educated individuals (red lines), the self-rated health trajectories of immigrants and non-immigrants do not differ (panel A and D), with the estimated values overlapping across the whole age span for both men and women. This result indicates that, as hypothesised, education protects immigrants from experiencing stronger weathering than non-immigrants.

For disability (Figure 4, panels A and D), we observe that, in line with the patterns found for self-rated health, the lowest educated have a higher probability of having a disability while the highest educated have a lower probability of having a disability across the whole age span. Focusing on the disability gap between immigrants and non-immigrants, we see that like for self-rated health, the lowest educated immigrants have an advantage at younger ages and a disadvantage at older ages. However, unlike for self-rated health, we observe an immigrant disadvantage at higher levels of education. Immigrants have a higher probability of having a disability until around age 60, when a converging trend starts for both sexes. It is worth noting that at younger ages (30 to ~40, panels A and D), there are no significant differences in the probability of having a disability between the lower and the higher educated immigrants of both sexes.

The role of income and marital status

When estimating the associations in specific marital status/income groups, we are interested in comparing the differences between immigrants and non-immigrants in the self-rated health (Figure 3) and disability trajectories (Figure 4) of the most advantaged socio-economic group (married individuals with high income, panels B for men and panels E for women in both

figures) and the most disadvantaged group (unmarried individuals with low income, panels C for men and panels F for women in both figures). We first focus on self-rated health (Figure 3). Across the whole age span, we observe lower overall estimates (and thus better health) among the most advantaged individuals (panels B and E) than among the most disadvantaged group (C and F). Among the most advantaged individuals, the gap between immigrants and non-immigrants is wide at younger ages, with immigrants having an advantage. However, the self-rated health trajectories of these individuals fully converge after the crossover occurs (at age 70.3). We find no significant differences by education in the self-rated health trajectories of immigrant men by education until age ~50. Starting at age ~50, education seems to play a more important role until age ~70, when we observe a convergence among immigrants with primary and tertiary education. Among non-immigrants men, differences by education persist, including in the most advantaged group.

Additionally, a more linear declining trend in self-rated health is observed among men, irrespective of their immigration status, education, marital status, and income; while a more curvilinear declining trend is observed among women. This implies that self-rated health declines more quickly among men than among women. In the case of disability, the shape of the trend is more similar among men and women.

Sensitivity checks

Results of the sensitivity checks are available in the online supplementary material. First, we run models without inverse probability weights in order to estimate the magnitude of the bias correction (results not shown).

Second, we run models imputing the outcome missing values due to loss to follow-up (self-rated health: Figure A1; disability: Figure A2). We impute values only from ages 50 to ages 80 using

the last observed outcome value and up to three years after loss to follow-up. For both self-rated health and disability, results without weights slightly underestimate the health disadvantage of immigrants at older ages, revealing narrower health gaps; however, the differences are qualitatively very similar. Results from the imputed models are quantitatively and qualitatively unchanged compared to the weighted models shown in the paper. Models without imputed values, which do not account for the loss to follow-up (or the so-called "salmon bias"), underestimate the more rapid ageing of immigrants compared to the weighted and imputed models. We interpret this result as indicating that if we were to observe the health of individuals who out-migrated, the immigrant disadvantage at older ages would be even more striking than the disadvantage that is currently observed.

Third, we stratify the models by country of birth (self-rated health: Figure A3; disability: Figure A4), focusing on the largest immigrant groups: Turkey, Italy, Poland, or other countries. Due to sample size problems, we can only show the overall health trajectories by age, but we include education as a control. The overall pattern of a more rapid health deterioration by age is observed for all subgroups, with some differences found in the size of the gap compared to non-immigrants. For both outcomes, the fastest health declines and the largest differences compared to non-immigrants are observed for immigrants born in Turkey across all ages. A very rapid health decline at younger ages that slows down in middle ages is observed for immigrants born in Italy. It is worth noting that the particularly steep decline found for immigrants from Italy is also partly due to the very good health of these immigrants at young ages. Men who immigrated from Italy show a pattern of self-rated health selection at exit that results in a slower health decline at older ages, particularly starting from around age 65 (statutory pension age). This finding is most likely attributable to a high proportion of these men going back to their origin country upon retirement.

Immigrants from Poland display a pattern that is very similar to the average trend among immigrants, with a steeper health decline being observed at older ages (70+), except in the case of disability among women, for whom a slower health decline at older ages (70+) is found.

Discussion

In this paper, we test the joint role of age and sex on the weathering of immigrants and non-immigrants, and investigate the protective role of education. Weathering is the process through which cumulative and stress-mediated wear and tear on cellular integrity leads to accelerated ageing, the early onset of chronic diseases, and excess mortality among marginalised groups, including immigrants (Jones et al 2019). This process can be interpreted as a physical consequence of the social inequality experienced by immigrants in the receiving context. Since age has been shown to be not only an indicator of biological development, but also a reflection of the ways in which social inequality, discrimination, or bias in exposures to psychosocial or environmental hazards may differentially affect the health of certain groups (Wildsmith 2002), we argue that this paper shows how the physical consequences of social inequalities in the form of health outcomes differ between non-immigrants and immigrants.

First, we observe that immigrants are ageing in poorer self-perceived health, and with a higher probability of having a physical limitation. We show that at younger ages, immigrants have better health than non-immigrants, irrespective of their sex and education. However, we also find that the health of immigrants deteriorates at a faster pace, which results in a clear and strong immigrant health disadvantage at older ages. Second, we find evidence that high education is linked to narrower health gaps between immigrants and non-immigrants, while low education is linked to higher levels of poor health, and, most importantly, to wider health gaps between

immigrants and non-immigrants. Our results indicate that education buffers the health differentials between immigrants and non-immigrants by age and sex: i.e., at higher levels of education (higher than high school), the health gap between immigrants and non-immigrants is reduced at all ages; while at lower levels of education (less than a high school diploma), the health gaps are more accentuated, with immigrants being in better health at younger ages, and in much poorer health at older ages.

We also find that being married and having a high income is protective to some extent: i.e., among the most advantaged individuals, the health gaps between immigrants and non-immigrants are narrower, as are the observed educational gaps. Finally, we find that there are sex differences in the differential weathering process between immigrants and non-immigrants, with some differences depending on the outcome. Among women, the age at crossover occurs earlier than it does among men for both outcomes. The health gap after the crossover occurs is wider among women, although self-rated health converges among women at older ages, whereas it continues to diverge among men. In the case of disability, the health gap between immigrants and non-immigrants after crossover occurs is wider among women, with the trend towards convergence at older ages being less strong.

This study is not without limitations. First, as was mentioned above, we use very broad education categories, as we do not have access to information about the country where the degree was obtained. A given educational level may have a different qualitative meaning across different cultures, and our analytical strategy does not fully control for this bias. However, some considerations reassure us that our results are robust. First, our results by education go in the expected direction, and are corroborated by previous literature showing that inequalities are wider at lower levels of education. If our classification approach suffered from misclassification

bias, our results should have reflected unexpected patterns. Given that we found striking differences by educational level, we are confident that this categorisation, although crude, is efficient in explaining the observed health disparities with age between immigrants and non-immigrants. Second, our analyses are further adjusted by income, which is a solid socio-economic status indicator and a strong predictor of health. This further adjustment using an additional socio-economic status indicator makes us confident about the robustness of our results.

Second, we cannot fully control for the out-migration bias; i.e., the so–called "salmon bias" (Abraído-Lanza et al 1999), or healthy remigration (Wallace & Kulu 2014). In fact, information on the health status of individuals who have left Germany to go back to their origin country, or who have emigrated to a third country, is not available. There is conflicting evidence regarding how health influences return migration that supports both selection for poor health (Abraído-Lanza et al 1999; Riosmena et al 2013) and selection for good health (Sander 2008). Immigrants may return to their home country when they are gravely ill; when they reach pension age; or alternatively, when they are healthy. However, the sensitivity analyses previously discussed showed that in our data, poor health is linked to a higher probability of out-migrating or loss to follow-up. It therefore appears that out-migration produces a bias towards an underestimation of poor health. Therefore we can safely assume that our results would reflect even stronger inequalities, had we had complete information on the health conditions of individuals who out-migrated.

Third, due to sample size issues, we could not fully explain the observed patterns of weathering by country of birth. In particular, we were unable to run stratified models by education and by country of birth. Thus, we could not test whether marital status and income help to explain the differences in healthy ageing trajectories across origins – by country of birth. However, we show the overall weathering process by country of birth, and control for education, finding similar

patterns across origins, albeit with some differences in the magnitude of the gap with non-immigrants.

Fourth, specific to the analyses on self-rated health, it is important to note that immigrants may consider their non-migrant counterparts in their country of birth as their health reference group, who may have worse health on average, rather than non-immigrants Germans, who may have better health on average. However, we found very similar patterns for self-rated health and disability in the observed health gaps, which makes us confident about the robustness of the results.

Fifth, the health of ageing immigrants may deteriorate due to other risk factors that were not measured in the data, and that we could not consider in our analyses. A further step towards understanding why immigrants age in poorer health may involve taking discrimination pathways into account, including discrimination in health care access. Despite these limitations, this paper provides a novel contribution to the literature on how structural factors, both separately and combined, can produce and exacerbate health inequalities between immigrants and non-immigrants with age.

To conclude, the differential process of ageing in poorer health we observed is likely be exacerbated as more immigrants enter ages at which they face a higher risk of developing health frailties. If prominent receiving countries like Germany do not design and implement specific policies to address social inequalities between immigrants and non-immigrants, the more rapid decline in health among immigrants is likely to become a public health issue with consequences for the sustainability of the overall health care system. As highlighted by our results, these policies should be particularly targeted at those individuals with lower levels of education and the greatest economic disadvantages, as these conditions are also linked to lower levels of integration.

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Appendix

Table A1. The relationship between the intersection of age, immigration status, and sex and self-rated health. Estimates from pooled OLS models. Men aged 30-80, SOEP waves 1994-2019, Germany. Models weighted with inverse probability weighting.

	Total population		Primary education		Secondary education		Tertiary education	
	M1_tot	M2_tot	M1_pr.	M2_pr.	M1_sec.	M2_sec.	M1_ter.	M2_ter.
Intercept	2.156 (0.008)***	2.294 (0.008)***	2.481 (0.035)***	2.583 (0.037)***	2.188 (0.010)***	2.291 (0.011)***	1.997 (0.013)***	2.125 (0.016)***
Age components of B-splines								
BS 1	0.469 (0.023)***	0.709 (0.023)***	0.410 (0.114)***	0.526 (0.114)***	0.539 (0.029)***	0.697 (0.029)***	0.411 (0.039)***	0.636 (0.040)***
BS 2	0.727 (0.016)***	0.719 (0.016)***	0.871 (0.086)***	0.878 (0.086)***	0.824 (0.021)***	0.796 (0.021)***	0.623 (0.027)***	0.620 (0.027)***
BS 3	0.961 (0.014)***	0.912 (0.014)***	0.691 (0.067)***	0.681 (0.067)***	0.972 (0.018)***	0.917 (0.018)***	1.011 (0.024)***	0.990 (0.025)***
Immigration status (ref. non-immigrant)								
Immigrant	-0.005 (0.043)	-0.112 (0.045)*	-0.237 (0.092)**	-0.330 (0.097)***	-0.031 (0.059)	-0.100 (0.064)	-0.090 (0.096)	-0.003 (0.101)
Age components of B-splines x immigration status (ref. BS1 x non-immigrant)								
BS1 × Immigrant	-0.037 (0.109)	0.049 (0.108)	0.025 (0.242)	0.076 (0.243)	-0.111 (0.152)	0.015 (0.153)	0.368 (0.240)	0.474 (0.239)*
BS2 × Immigrant	0.365 (0.056)***	0.336 (0.056)***	0.209 (0.136)	0.188 (0.136)	0.346 (0.081)***	0.339 (0.081)***	-0.052 (0.119)	-0.123 (0.119)
BS3 × Immigrant	0.127 (0.069)+	0.159 (0.069)*	0.496 (0.153)**	0.481 (0.153)**	0.085 (0.097)	0.095 (0.097)	0.193 (0.150)	0.223 (0.149)
Marital status (ref. Unmarried)								
Married		0.016 (0.005)**		-0.096 (0.025)***		0.011 (0.006)+		0.033 (0.009)***
Income (ref. Low)								
Medium		-0.174 (0.006)***		-0.132 (0.027)***		-0.154 (0.007)***		-0.112 (0.012)***
High		-0.377 (0.006)***		-0.221 (0.035)***		-0.277 (0.007)***		-0.294 (0.012)***
Immigration status x marital status (ref. non-immigrant, unmarried)								
Immigrant × Married		0.047 (0.020)*		0.142 (0.046)**		0.031 (0.030)		-0.002 (0.040)
Immigration status x income (ref. non-immigrant, low)								
Immigrant × Medium		-0.016 (0.017)		-0.023 (0.041)		-0.004 (0.025)		-0.136 (0.043)**
Immigrant × High		-0.034 (0.019)+		0.035 (0.051)		-0.090 (0.030)**		-0.255 (0.041)***
Num.Obs.	196279	196279	13435	13435	121059	121059	61785	61785
R2	0.081	0.106	0.067	0.076	0.087	0.099	0.086	0.102
R2 Adj.	0.081	0.106	0.067	0.075	0.087	0.099	0.086	0.102

Table A2. The relationship between the intersection of age, immigration status, and sex and self-rated health. Estimates from pooled OLS models. Women aged 30-80, SOEP waves 1994-2019, Germany. Models weighted with inverse probability weighting.

	Total population		Primary education		Secondary education		Tertiary education	
	M1_tot	M2_tot	M1_pr.	M2_pr.	M1_sec.	M2_sec.	M1_ter.	M2_ter.
Intercept	**2.239 (0.007)*** **	**2.367 (0.008)*** **	**2.518 (0.026)*** **	**2.587 (0.028)*** **	**2.273 (0.009)*** **	**2.376 (0.010)*** **	**2.081 (0.013)*** **	**2.255 (0.016)*** **
Age components of B-splines								
BS 1	0.442 (0.022)***	0.634 (0.022)***	0.854 (0.073)***	0.953 (0.073)***	0.449 (0.027)***	0.598 (0.027)***	0.383 (0.042)***	0.531 (0.042)***
BS 2	0.572 (0.016)***	0.509 (0.016)***	0.227 (0.042)***	0.186 (0.042)***	0.535 (0.020)***	0.486 (0.020)***	0.727 (0.034)***	0.720 (0.034)***
BS 3	1.102 (0.013)***	1.024 (0.013)***	0.974 (0.036)***	0.942 (0.036)***	1.036 (0.017)***	0.981 (0.017)***	1.047 (0.031)***	0.965 (0.031)***
Immigration status (ref. non-immigrant)								
Immigrant	-0.079 (0.036)*	-0.058 (0.038)	-0.329 (0.063)***	-0.197 (0.068)**	-0.098 (0.057)+	-0.098 (0.062)	-0.029 (0.073)	0.025 (0.079)
Age components of B-splines x immigration status (ref. BS1 x non-immigrant)								
BS1 × Immigrant	0.129 (0.096)	0.238 (0.096)*	0.004 (0.167)	0.061 (0.168)	0.050 (0.157)	0.186 (0.158)	0.188 (0.200)	0.280 (0.199)
BS2 × Immigrant	0.650 (0.057)***	0.571 (0.057)***	1.082 (0.094)***	1.053 (0.095)***	0.652 (0.098)***	0.578 (0.098)***	0.020 (0.128)	-0.118 (0.128)
BS3 × Immigrant	0.095 (0.065)	0.108 (0.065)+	0.297 (0.102)**	0.218 (0.102)*	0.022 (0.112)	0.045 (0.112)	0.148 (0.154)	0.137 (0.153)
Marital status (ref. Unmarried)								
Married		0.026 (0.005)***		-0.005 (0.013)		0.004 (0.006)		0.058 (0.009)***
Income (ref. Low)								
Medium		-0.163 (0.005)***		-0.120 (0.015)***		-0.131 (0.007)***		-0.185 (0.012)***
High		-0.343 (0.006)***		-0.245 (0.020)***		-0.270 (0.007)***		-0.353 (0.012)***
Immigration status x marital status (ref. non-immigrant, unmarried)								
Immigrant × Married		-0.043 (0.017)*		-0.123 (0.030)***		0.010 (0.028)		-0.046 (0.034)
Immigrant × Medium		-0.036 (0.017)*		-0.037 (0.030)		-0.071 (0.028)*		-0.012 (0.039)
Immigrant × High		-0.090 (0.019)***		-0.038 (0.037)		-0.098 (0.032)**		-0.148 (0.038)***
Num.Obs.	219692	219692	31025	31025	133850	133850	54817	54817
R2	0.089	0.109	0.063	0.073	0.076	0.088	0.081	0.101
R2 Adj.	0.089	0.109	0.063	0.073	0.075	0.088	0.081	0.101

Table A3. The relationship between the intersection of age, immigration status, and sex and disability. Estimates from pooled OLS models. Men aged 30-80, SOEP waves 1994-2019, Germany. Models weighted with inverse probability weighting.

	Total population		Primary education		Secondary education		Tertiary education	
	M1_tot	M2_tot	M1_pr.	M2_pr.	M1_sec.	M2_sec.	M1_ter.	M2_ter.
Intercept	-1.103 (0.024)***	-0.954 (0.025)***	-0.819 (0.082)***	-0.706 (0.085)***	-1.029 (0.030)***	-0.925 (0.031)***	-1.396 (0.047)***	-1.241 (0.052)***
Age components of B-splines								
BS 1	0.615 (0.063)***	0.953 (0.065)***	1.017 (0.257)***	1.210 (0.260)***	0.660 (0.080)***	0.858 (0.081)***	0.479 (0.121)***	0.837 (0.125)***
BS 2	1.175 (0.040)***	1.209 (0.040)***	1.103 (0.196)***	1.090 (0.197)***	1.342 (0.050)***	1.330 (0.051)***	1.199 (0.070)***	1.223 (0.071)***
BS 3	1.730 (0.039)***	1.692 (0.039)***	1.666 (0.158)***	1.656 (0.161)***	1.706 (0.049)***	1.655 (0.050)***	1.870 (0.072)***	1.870 (0.073)***
Immigration status (ref. non-immigrant)								
Immigrant	0.158 (0.123)	-0.011 (0.130)	-0.369 (0.229)	-0.513 (0.241)*	0.209 (0.174)	0.002 (0.187)	0.498 (0.290)+	0.700 (0.302)*
Age components of B-splines x immigration status (ref. BS1 x non-immigrant)								
BS1 × Immigrant	-0.516 (0.300)+	-0.499 (0.305)	-0.342 (0.582)	-0.410 (0.590)	-0.848 (0.428)*	-0.729 (0.435)+	-0.449 (0.690)	-0.490 (0.698)
BS2 × Immigrant	0.518 (0.143)***	0.434 (0.144)**	0.946 (0.318)**	0.936 (0.319)**	0.394 (0.204)+	0.385 (0.206)+	-0.171 (0.306)	-0.359 (0.310)
BS3 × Immigrant	-0.109 (0.187)	-0.092 (0.188)	0.162 (0.368)	0.143 (0.370)	-0.087 (0.265)	-0.095 (0.268)	-0.499 (0.424)	-0.486 (0.426)
Marital status (ref. Unmarried)								
Married		0.028 (0.013)*		-0.091 (0.055)+		0.015 (0.015)		0.046 (0.024)+
Income (ref. Low)								
Medium		-0.208 (0.014)***		-0.204 (0.060)***		-0.165 (0.016)***		-0.155 (0.032)***
High		-0.504 (0.014)***		-0.308 (0.079)***		-0.329 (0.018)***		-0.416 (0.031)***
Immigration status x marital status (ref. non-immigrant, unmarried)								
Immigrant × Married		0.129 (0.051)*		0.185 (0.107)+		0.212 (0.076)**		-0.019 (0.102)
Immigration status x income (ref. non-immigrant, low)								
Immigrant × Medium		-0.045 (0.045)		0.068 (0.096)		-0.048 (0.064)		-0.326 (0.108)**
Immigrant × High		0.056 (0.051)		0.168 (0.124)		-0.104 (0.079)		-0.220 (0.106)*
Num.Obs.	71746	71746	4524	4524	43564	43564	23658	23658
AIC	88077.1	86579.7	5652.3	5629.7	54267.8	53899.3	26475.4	26193.3
Log.Lik.	-44030.567	-43275.87	-2818.144	-2800.858	-27125.878	-26935.633	-13229.703	-13082.667

Table A4. The relationship between the intersection of age, immigration status, and sex and disability. Estimates from pooled OLS models. Women aged 30-80, SOEP waves 1994-2019, Germany. Models weighted with inverse probability weighting.

	All M1	All M3	Primary M1	Primary M3	Secondary M1	Secondary M3	Tertiary M1	Tertiary M3
Intercept	-0.770 (0.020)***	-0.638 (0.022)***	-0.478 (0.066)***	-0.368 (0.069)***	-0.721 (0.025)***	-0.624 (0.027)***	-1.002 (0.040)***	-0.829 (0.045)***
Age components of B-splines								
BS 1	0.217 (0.056)***	0.487 (0.057)***	0.944 (0.180)***	1.031 (0.182)***	0.281 (0.071)***	0.497 (0.072)***	-0.009 (0.115)	0.190 (0.116)
BS 2	1.058 (0.038)***	1.002 (0.039)***	0.755 (0.106)***	0.757 (0.109)***	1.004 (0.048)***	0.940 (0.048)***	1.308 (0.085)***	1.315 (0.085)***
BS 3	1.704 (0.036)***	1.624 (0.036)***	1.576 (0.094)***	1.538 (0.095)***	1.607 (0.046)***	1.557 (0.046)***	1.780 (0.084)***	1.697 (0.085)***
Immigration status (ref. non-immigrant)								
Immigrant	-0.109 (0.094)	-0.193 (0.101)+	-0.163 (0.159)	-0.124 (0.173)	-0.478 (0.159)**	-0.626 (0.169)***	0.154 (0.188)	0.182 (0.203)
Age components of B-splines x immigration status (ref. BS1 x non-immigrant)								
BS1 × Immigrant	0.538 (0.248)*	0.610 (0.251)*	-0.504 (0.424)	-0.469 (0.430)	1.208 (0.420)**	1.322 (0.426)**	0.536 (0.503)	0.593 (0.507)
BS2 × Immigrant	0.258 (0.146)+	0.189 (0.147)	0.825 (0.249)***	0.757 (0.253)**	0.321 (0.239)	0.324 (0.241)	-0.380 (0.313)	-0.536 (0.318)+
BS3 × Immigrant	0.406 (0.178)*	0.450 (0.180)*	0.459 (0.280)	0.426 (0.282)	0.649 (0.303)*	0.734 (0.305)*	-0.025 (0.403)	-0.063 (0.409)
Marital status (ref. Unmarried)								
Married		0.056 (0.011)***		-0.086 (0.033)**		0.041 (0.014)**		0.096 (0.024)***
Income (ref. Low)								
Medium		-0.181 (0.013)***		-0.124 (0.036)***		-0.150 (0.016)***		-0.176 (0.031)***
High		-0.453 (0.014)***		-0.253 (0.050)***		-0.357 (0.017)***		-0.436 (0.031)***
Immigration status x marital status (ref. non-immigrant, unmarried)								
Immigrant × Married		0.054 (0.041)		-0.012 (0.076)		0.094 (0.068)		0.113 (0.081)
Immigration status x income (ref. non-immigrant, low)								
Immigrant × Medium		-0.017 (0.043)		0.020 (0.075)		0.037 (0.069)		-0.190 (0.092)*
Immigrant × High		-0.038 (0.047)		0.018 (0.095)		-0.062 (0.078)		-0.219 (0.092)*
Num.Obs.	80405	80405	10418	10418	49084	49084	20903	20903
AIC	100343.2	98996.6	12269.5	12218.1	62330.5	61838.4	24426.4	24134.6

Log.Lik.	-50163.606	-49484.322	-6126.729	-6095.031	-31157.247	-30905.201	-12205.22	-12053.298

Tables and figures

Table 1. Descriptive statistics of the samples. Individuals aged 30-80, Germany, SOEP waves 1994-2019.

	Outcome: self-rated health				Outcome: disability			
	Non-immigrants		Immigrants		Non-immigrants		Immigrants	
	Men, N = 24,739	Women, N = 26,403	Men, N = 3,026	Women, N = 3,233	Men, N = 17,809	Women, N = 19,657	Men, N = 2,079	Women, N = 2,398
Mean age	47.4 (13.7)	46.7 (13.9)	48.5 (10.6)	46.4 (10.6)	49.4 (13.6)	48.7 (13.7)	50.7 (12)	48.3 (11.2)
Education								
Primary	1,421 (6%)	3,530 (13%)	1,117 (37%)	1,333 (41%)	995 (6%)	2,365 (12%)	701 (34%)	911 (38%)
Secondary	15,447 (62%)	16,617 (63%)	1,309 (43%)	1,131 (35%)	11,072 (62%)	12,508 (64%)	929 (45%)	872 (36%)
Tertiary	7,871 (32%)	6,256 (24%)	600 (20%)	769 (24%)	5,742 (32%)	4,784 (24%)	449 (22%)	615 (26%)
Income								
Low	6,676 (27%)	8,899 (34%)	1,081 (36%)	1,178 (36%)	5,172 (29%)	6,744 (34%)	799 (38%)	938 (39%)
Medium	8,168 (33%)	8,406 (32%)	1,167 (39%)	1,198 (37%)	6,162 (35%)	6,542 (33%)	854 (41%)	901 (38%)
High	9,895 (40%)	9,098 (35%)	778 (26%)	857 (27%)	6,475 (36%)	6,371 (32%)	426 (21%)	559 (23%)
Marital status								
Unmarried	7,744 (31%)	9,670 (37%)	418 (14%)	715 (22%)	5,552 (31%)	7,188 (37%)	314 (15%)	579 (24%)
Married	16,995 (69%)	16,733 (63%)	2,608 (86%)	2,518 (78%)	12,257 (69%)	12,469 (63%)	1,765 (85%)	1,819 (76%)
Mean self-rated health	3.6 (0.9)	3.5 (1.0)	3.4 (1.1)	3.3 (1.0)	-	-	-	-
Disability					-	-	-	-
Yes	-	-	-	-	6,221 (35%)	8,041 (41%)	842 (41%)	1,111 (46%)
Countries of birth								
Italy			208 (7%)	146 (5%)			136 (7%)	95 (4%)
Others			2,130 (70%)	2,345 (73%)			1,477 (71%)	1,748 (73%)
Poland			260 (9%)	388 (12%)			205 (10%)	307 (13%)
Turkey			428 (14%)	354 (11%)			261 (13%)	248 (10%)
Foreing-born total			3,026 (11%)	3,233 (11%)			2,079 (11%)	2,398 (11%)

Figure 1. Self-rated health trajectories by age and immigration status, stratified by sex. Individuals aged 30-80, Germany, SOEP waves 1994-2019 (full estimates in Tables A1-A4). Models weighted with inverse probability weighting.

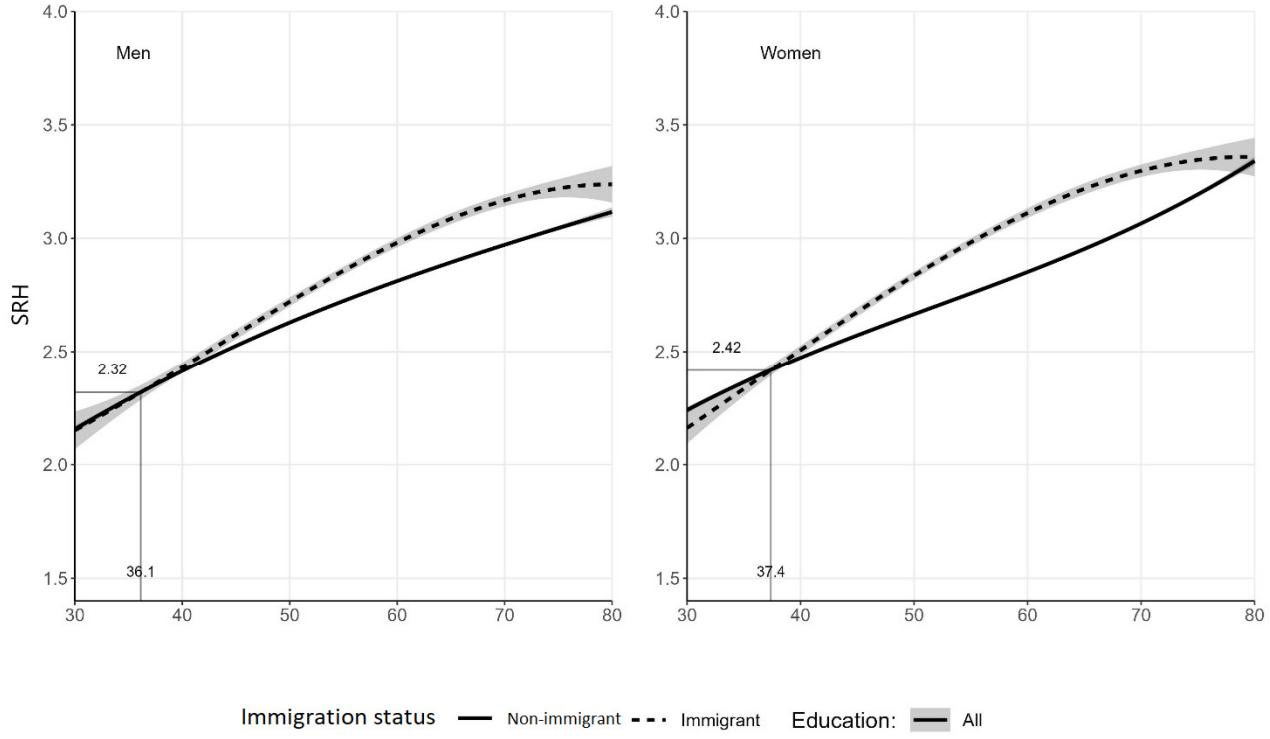


Figure 2. Disability trajectories by age and immigration status, stratified by sex. Individuals aged 30-80, Germany, SOEP waves 1994-2019 (full estimates in Tables A1-A4). Models weighted with inverse probability weighting.

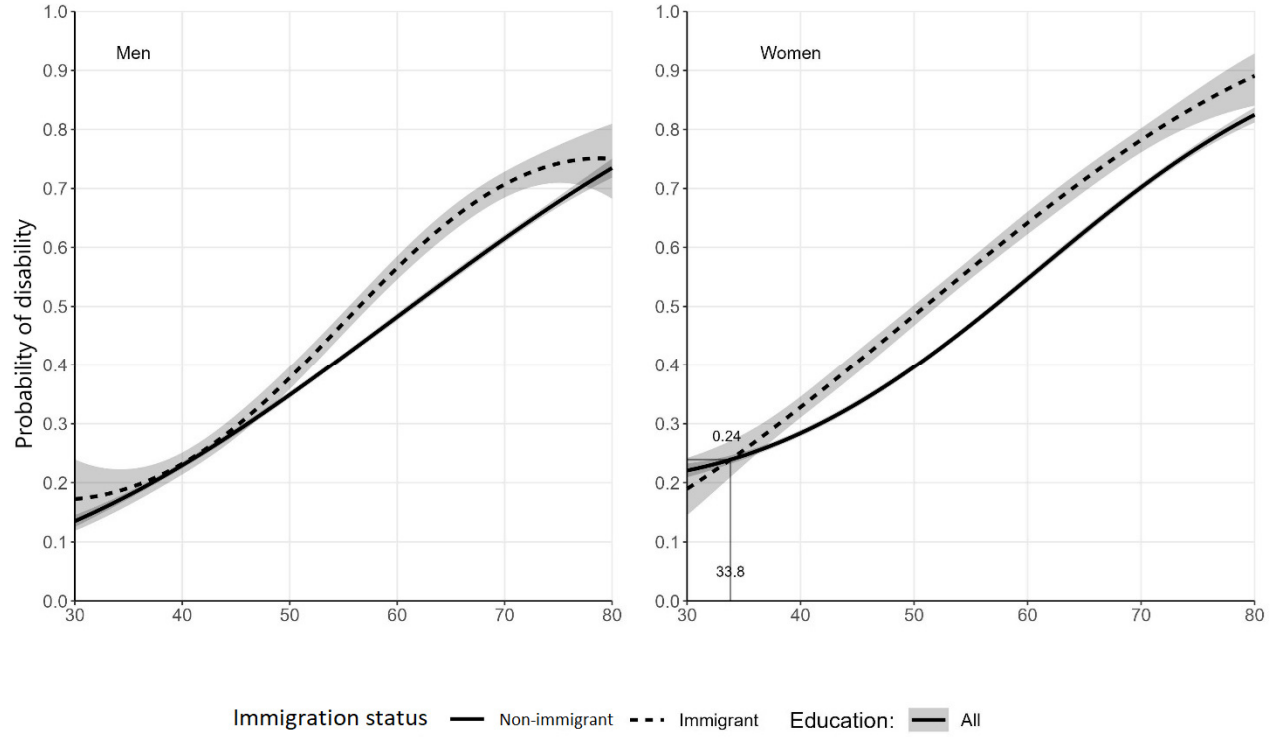
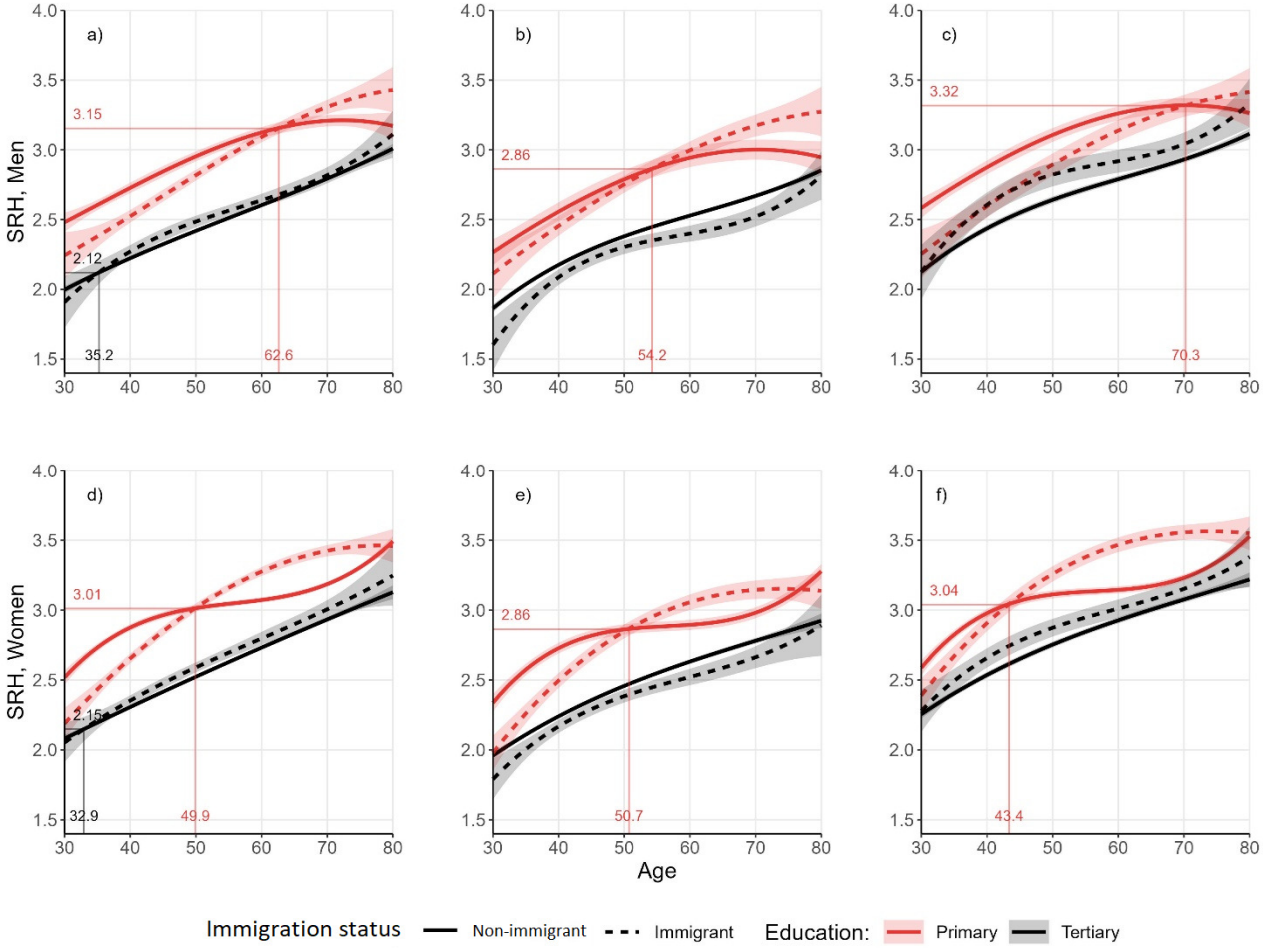
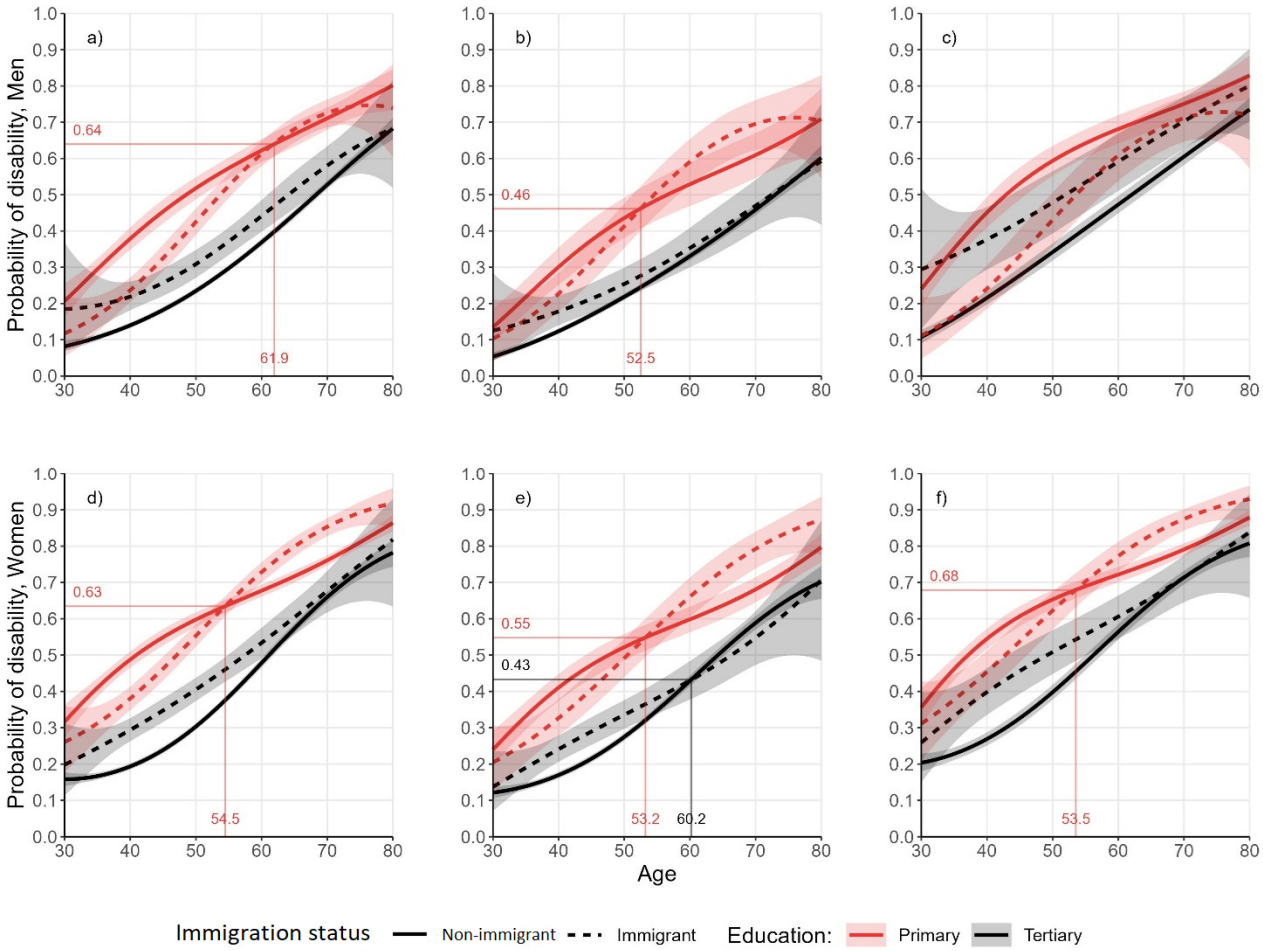


Figure 3. Self-rated health trajectories by age and immigration status, stratified by sex and education. Individuals aged 30-80, Germany, SOEP waves 1994-2019 (full estimates in Tables A1-A4). Models weighted with inverse probability weighting.



Notes: Panel A: men, total; panel B: married men with high income; panel C: unmarried men with low income; panel D: women, total; panel E: married women with high income; panel F: unmarried women with low income

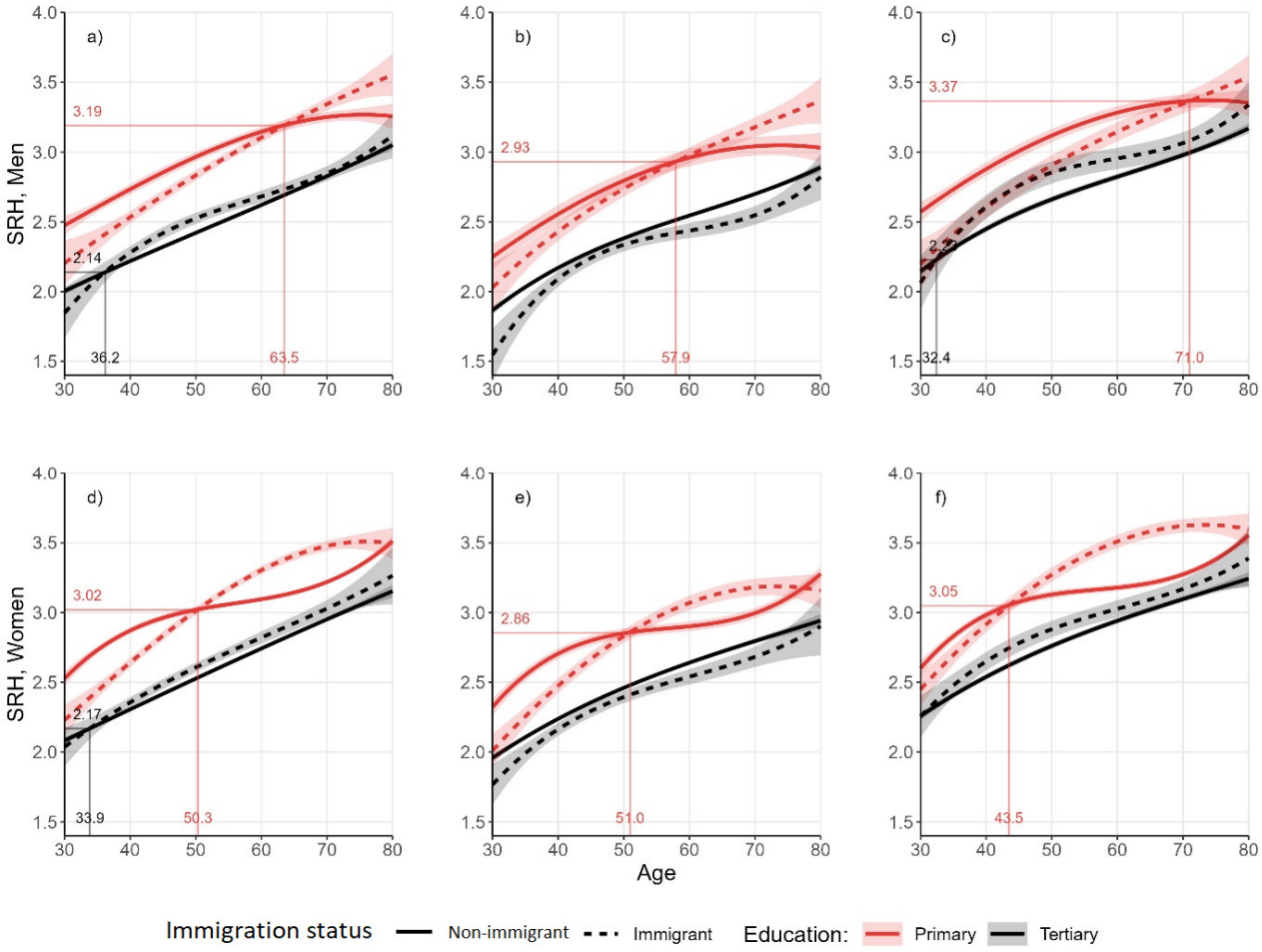
Figure 4. Disability trajectories by age and immigration status, stratified by sex and education. Individuals aged 30-80, Germany, SOEP waves 1994-2019 (full estimates in Tables A1-A4). Models weighted with inverse probability weighting.



Notes: Panel A: men, total; panel B: married men with high income; panel C: unmarried men with low income; panel D: women, total; panel E: married women with high income; panel F: unmarried women with low income

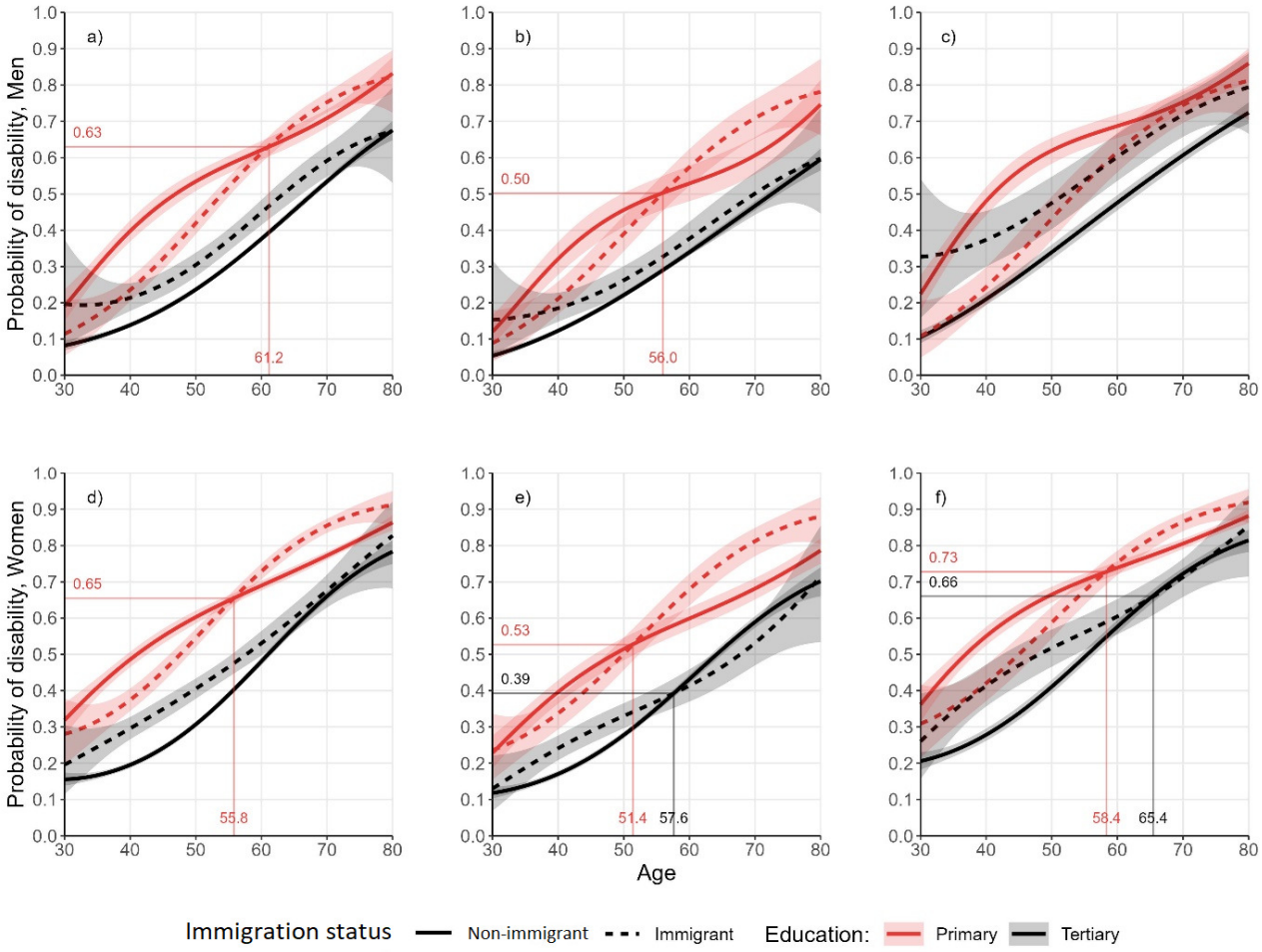
Supplementary material

Figure OA5. Self-rated health trajectories by age and immigration status, stratified by sex and education. Individuals aged 30-80, Germany, SOEP waves 1994-2019. The models include imputed values of self-rated health for individuals lost to follow-up. The imputation is based on the last self-rated health value prior to loss to follow-up, up until 3 years after loss to follow-up. Values are Imputed only between ages 50-80.



Notes: Panel A: men, total; panel B: married men with high income; panel C: unmarried men with low income; panel D: women, total; panel E: married women with high income; panel F: unmarried women with low income

Figure OA6. Disability trajectories by age and immigration status, stratified by sex and education. Individuals aged 30-80, Germany, SOEP waves 1994-2019. The models include imputed values of disability for individuals lost to follow-up. The imputation is based on the last disability value prior to loss to follow-up, up until 3 years after loss to follow-up. Values are Imputed only between ages 50-80.



Notes: Panel A: men, total; panel B: married men with high income; panel C: unmarried men with low income; panel D: women, total; panel E: married women with high income; panel F: unmarried women with low income

Figure OA7. Self-rated health trajectories by age and immigration status, stratified by sex and countries of birth. Models adjusted by education and weighted with inverse probability weighting. Individuals aged 30-80, Germany, SOEP waves 1994-2019.

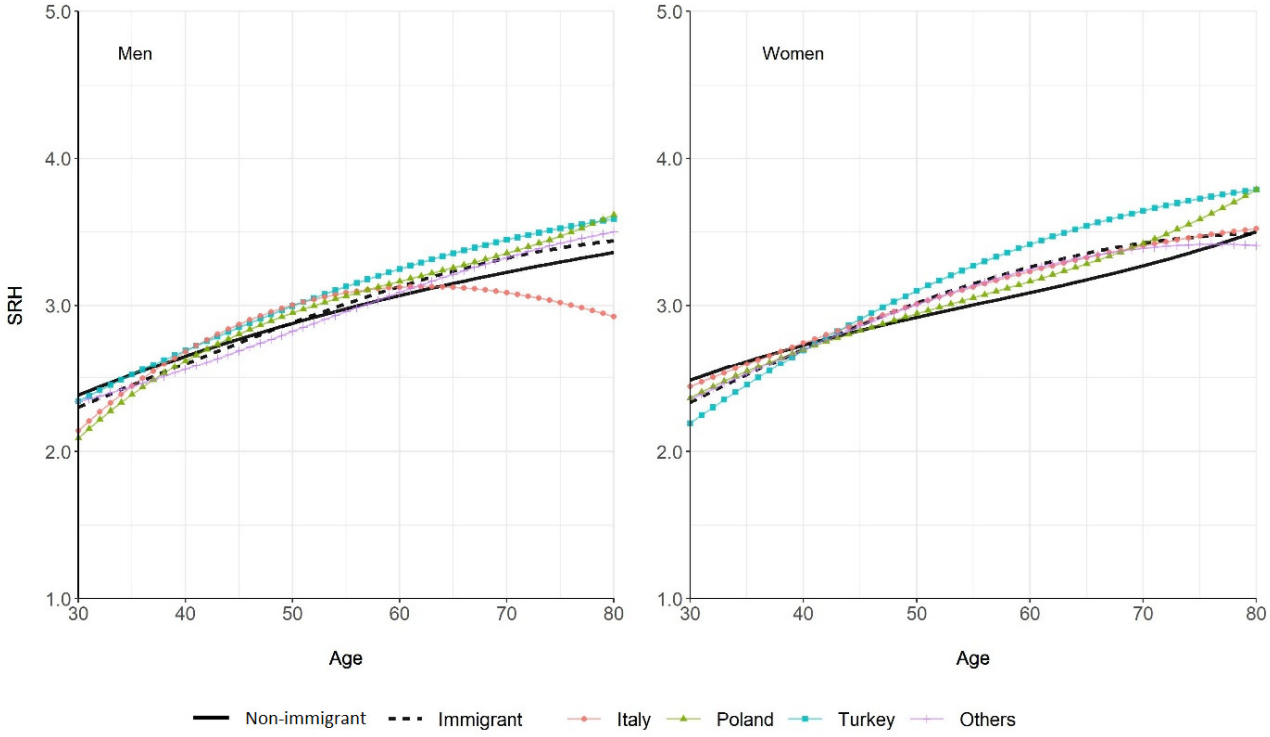


Figure OA8. Disability trajectories by age and immigration status, stratified by sex and countries of birth. Models adjusted by education and weighted with inverse probability weighting. Individuals aged 30-80, Germany, SOEP waves 1994-2019.