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The effect of retirement on biomedical and behavioral risk factors for cardiovascular and metabolic disease

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ABSTRACT

Retirement is a major life event potentially associated with changes in relevant risk factors for cardiovascular and metabolic conditions. This study analyzes the effect of retirement on behavioral and biomedical risk factors for chronic disease, together with subjective health parameters using Southern German epidemiological data. We used panel data from the KORA cohort study, consisting of 11,168 observations for individuals 45–80 years old. Outcomes included health behavior (alcohol, smoking, physical activity), biomedical risk factors (body-mass-index (BMI), waist-to-hip ratio (WHR), glycosylated hemoglobin (HbA1c), total cholesterol/HDL quotient, systolic/diastolic blood pressure), and subjective health (SF12 mental and physical scales, self-rated health). We applied a parametric regression discontinuity design based on age thresholds for pension eligibility. Robust results after p-value corrections for multiple testing showed an increase in BMI in early retirees (at the age of 60) [$\beta = 1.11$, corrected p-val. < 0.05] and an increase in CHO/HDL in regular retirees (age 65) [$\beta = 0.47$, corrected p-val. < 0.05]. Stratified analyses indicate that the increase in BMI might be driven by women and low educated individuals retiring early, despite increasing physical activity. The increase in CHO/HDL might be driven by men retiring regularly, alongside an increase in subjective physical health. Blood pressure also increased, but the effect differs by retirement timing and sex and is not always robust to sensitivity analysis checks. Our study indicates that retirement has an impact on different risk factors for chronic disease, depending on timing, sex and education. Regular male, early female, and low educated retirees should be further investigated as potential high-risk groups for worsening risk factors after retirement. Future research should investigate if and how these results are linked: in fact, especially in the last two groups, the increase in leisure time physical activity might not be enough to compensate for the loss of work-related physical activity, leading thus to an increase in BMI.

1. Introduction

Cardiovascular and metabolic diseases are among the major causes of morbidity and mortality in the population in high and middle income countries (World Health Organization, 2018). They are associated with a large economic burden on healthcare systems (Bloom et al., 2012), with extensive losses in quality of life (Glasgow et al., 1997; Juenger et al., 2002) and productivity (Chaker

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et al., 2015; Pedron et al., 2019). Their incidence increases sharply beyond the age of 55 (Tamayo et al., 2016; Mozaffarian et al., 2015), making this age group a primary target of public health preventive measures. Among the most prominent modifiable risk factors for these illnesses are unhealthy behaviors, whereas other critical determinants include physical and psychosocial occupational stressors and socioeconomic conditions (Nyberg et al., 2013; Winkleby et al., 1992).

In the life of a working individual, retirement marks a major event, often perceived as a transition from middle age to old age, which goes along with a reshaping of one's own identity and daily activities (Atchley, 1976; Gall et al., 1997; Palmore et al., 1984). As such, retirement is connected with several important changes in the aforementioned risk factors for chronic disease, both in a positive and negative way (Kasl and Jones, 2000). On the one hand, for those who strongly identify themselves with their role as working individuals, this transition could be connected with a loss in sense of purpose and social contacts. On the other hand, at retirement individuals are relieved from occupational strains and can dedicate themselves to other meaningful and fulfilling activities (Atchley, 1976; Gall et al., 1997; Palmore et al., 1984). Through the reshaping of daily activities, individuals could become more or less active than during their working age, with direct and lasting consequences for their cardiovascular and metabolic health (Zantinge et al., 2013).

Careful consideration of potential health effects of retirement is mandatory to shape effective and successful labor market and health policies aimed at keeping the older workforce active, extending working life, and reshaping flexible retirement exit routes. These mark important societal and political challenges, that will influence the sustainability of healthcare and pension systems in the next decades (Carone et al., 2016). Despite an increased interest in the literature regarding the effect of retirement on health, evidence concerning potential effects for physical health and the underlying mechanisms remains inconclusive if not completely lacking. Understanding the effect of retirement on biomedical and behavioral risk factors for chronic diseases is crucial. In fact, risk factors are directly related to the aforementioned changes at retirement and might have long lasting consequences on cardiovascular and metabolic health later in life, on disability, longevity and health care costs.

In our study, we aimed at estimating the causal effect of retirement on a large set of biomedical and behavioral risk factors for cardiovascular and metabolic disease, including glycosylated hemoglobin, total cholesterol/HDL-cholesterol ratio, blood pressure, body-mass-index (BMI), waist-to-hip ratio (WHR), physical activity, smoking and alcohol consumption. We also investigated the effect on subjective health indicators. We analyzed the research question by using a German epidemiological dataset, which included objectively measured and validated observations on risk factors and self-reported health behavior information.

Estimating the effect of retirement on health is not straightforward. In fact, selection problems and potential unobserved confounding might considerably bias the results, jeopardizing the identification of a causal effect (Nishimura et al., 2018; Barnay, 2016). Therefore, in our study we used a regression discontinuity design, exploiting the retirement age thresholds as exogenous sources of variation to obtain valid causal effect estimates (Lee and Lemieux, 2010). The same method was already employed by other authors for the identification of the effects of retirement on a wide range of health outcomes (Coe and Zamarro, 2011; Eibich, 2015; Godard, 2016; Insler, 2014; Johnston and Lee, 2009; Müller and Shaikh, 2018; Zhao et al., 2017). However, unlike many of these studies on the effect of retirement using a regression discontinuity design, we applied a parametric identification strategy, which allowed us to include a larger period of time around the cutoff by choosing the correct modelling of the health-age relationship (Lee and Lemieux, 2010). Furthermore, we extensively explored the robustness of our findings using a set of specification curves (Christensen and Miguel, 2018; Simonsohn et al., 2015).

Our study contributes to the available literature in two ways. First, we are among the first to estimate the causal effect of retirement on a large set of biomedical risk factors for chronic cardiovascular and metabolic conditions (Behncke, 2012). Not only do these represent clinical parameters, directly relevant in the daily clinical practice. Estimating the impact of retirement on these outcomes might also help in understanding the concrete long run effects of retirement on cardiovascular and metabolic health, providing insights in an area in which evidence is either scarce or even lacking. Second, by including a large set of behavioral parameters, subjective health indicators and heterogeneity sources, we are able to provide a complete picture of the effects of retirement, identifying effects, relevant mechanisms and risk groups. Furthermore, this allows us to establish a link between previously reported changes in health behavior and effects on chronic diseases, providing evidence-based targets for public health policies.

Our results show that regular retirement (at the age of 65) leads to an increase in CHO/HDL levels. Stratified results indicate that this increase might be driven especially by men retiring regularly and is accompanied by increasing subjective physical health. Furthermore, early retirement (age 60) leads to a robust increase in BMI. This is confirmed by an increasing tendency in WHR, despite an increase in physical activity. Early female and low educated retirees seem to be particularly affected by these negative changes. Combining these results, a possible interpretation is that these groups are not able to compensate the loss in work-related physical activity with enough leisure time physical activity after early retirement, leading thus to an increase in the risk of cardiovascular and metabolic disease later in life. Yet, this interpretation should be appreciated with caution and further investigated especially for women, due to their more selective labor market participation. Nevertheless, following our current results, men retiring regularly and women and low educated individuals retiring early should be considered as high-risk targets for behavioral interventions for a healthy adaptation to retirement, targeting also the other risk factors considered, which did not show any change.

This paper is structured as follows. First, a literature overview of the most relevant evidence on the effect of retirement on health is presented. Hereby, we particularly focus on behavioral and biomedical risk factors, chronic disease incidence, and subjective health. In the “Methods” section the analyzed survey data and empirical strategy are presented. Follows a “Results” section, which also contains the heterogeneity analysis and extensive robustness checks. Concluding we discuss, interpret and compare our results with the available literature.

2. Related literature

In the last few years, the question regarding the effect of retirement on health has received increasing attention. The empirical evidence shows a generally positive impact of retirement on subjective health and behavior. Studies which estimated the causal effect of retirement used mainly instrumental variables strategies and generally showed a positive effect of retirement on physical activity and smoking cessation (Eibich, 2015; Insler, 2014; Müller and Shaikh, 2018; Zhao et al., 2017; Celidoni and Rebba, 2017; Kämpfen and Maurer, 2016; Motegi et al., 2016; Oshio and Kan, 2017; Zhu, 2016). Furthermore, most studies evidenced an increase in subjective health (Coe and Zamarro, 2011; Eibich, 2015; Insler, 2014; Johnston and Lee, 2009; Oshio and Kan, 2017; Zhu, 2016; Blake and Garrouste, 2013; Coe and Lindeboom, 2008;

DeGrip et al., 2012; Hessel, 2016; Mazzonna and Peracchi, 2015; Neuman, 2007; Kolodziej and Garcia-Gomez, 2019; Messe and Wolff, 2019), with few exceptions showing either a negative or no effect (Johnston and Lee, 2009; Sahlgren, 2012; Dave et al., 2006). A recent study by Anxo et al. (2019) revealed that individuals who continued working past age 65 reported on average a better self-rated health during retirement than those who retired at 65. The effect however was found only in the short run, since no difference was present after 6 years.

However, a closer look at the mental health component displays no effects of retirement on depression, measured with different scales (Coe and Zamarro, 2011; Blake and Garrouste, 2013; Neuman, 2007; Latif, 2013; Heller-Sahlgren, 2017). Furthermore, studies investigating the impact of retirement on cognitive functioning report accelerated cognitive decline after retirement (Bonsang et al., 2012; Clouston and Denier, 2017; Mazzonna and Peracchi, 2012; Rohwedder and Willis, 2010), while some other studies detected unclear effects (Coe and Zamarro, 2011; Coe et al., 2012; de Grip et al., 2015). A recent study using European SHARE data showed that the effect of retirement on cognition is more sophisticated and strongly depends on timing: for regular retirees it has a detrimental effect, while for early retirees it has rather a protective effect (Celidoni et al., 2017).

Regarding physical health, the empirical evidence has not yet been able to disentangle the complex and ambiguous effect of retirement, producing scarce and mixed findings. This is probably not only due to the inherent complexity of modelling this transition (Nishimura et al., 2018; Barnay, 2016), but also to scarce data availability of objectively measured physical health parameters in large socioeconomic surveys.

Specifically relevant for the sake of the present work are studies investigating the association between retirement and the risk of chronic cardiovascular and metabolic conditions, which generally reported mixed findings (Insler, 2014; Johnston and Lee, 2009; Behncke, 2012; Hessel, 2016; Neuman, 2007; Horner and Cullen, 2016; Shai, 2018; Moon et al., 2012; Xue et al., 2019). However, results of instrumental variables approaches showed no effects of retirement on the risk of chronic conditions or composite indices, which include indistinctly a large number of cardiovascular and metabolic conditions such as myocardial infarction, stroke, cardiovascular disease, hypertension and diabetes (Johnston and Lee, 2009; Hessel, 2016; Neuman, 2007; Horner and Cullen, 2016). Here, the risk of diabetes marks an exception since Horner and Cullen (2016) reported increased risk, while Insler (2014) noted a protective effect of retirement for this condition. The study by Behncke (2012) on the effect of retirement on chronic cardiovascular conditions and metabolic syndrome as a risk factor is directly relevant for the present study. The author used data from England and an identification strategy primarily based on nonparametric matching, which leaves open concerns of potential residual bias. In contrast, we draw on a regression discontinuity design to address such concerns of bias and provide new evidence for Germany. Finally, while Behncke (2012) primarily used a composite outcome based on self-reported diagnoses (metabolic syndrome), we use single and objectively measured biomarkers, which can also capture preclinical conditions.

Another possible reason why no effect of retirement on cardiovascular disease and diabetes could be observed is that, in the short run, the effect of retirement might rather concern their biomedical risk factors, which respond quicker to changes in lifestyle and which are directly related to an increased risk for chronic conditions later in life. However, evidence regarding the causal effect of retirement on biomedical risk factors for chronic diseases is scarce and mainly focused on weight or body-mass-index (BMI). Most studies reported a modest increase (Godard, 2016; Behncke, 2012; Chung et al., 2009; Goldman et al., 2008), while others found either negative or no effects (Eibich, 2015; Johnston and Lee, 2009). Few studies have investigated the association with blood biomarkers, such as blood pressure and cholesterol levels (Behncke, 2012; Xue et al., 2017), as emerges also from a recent review (Xue et al., 2019). However, they differ substantially in their methodology, so that concerns regarding residual bias remain. Furthermore, in this context, very few studies have investigated causal effects on both health behavior and health outcomes based on one unique dataset, allowing them to draw conclusions regarding possible underlying mechanisms (Eibich, 2015; Insler, 2014; Zhu, 2016). Available studies report no effects on alcohol consumption, increased physical activity and reduced smoking, together with increased self-rated health (Eibich, 2015; Godard, 2016; Insler, 2014; Zhu, 2016), and showed again different effects on BMI (Eibich, 2015; Godard, 2016). Interestingly, this leads to different scenarios and interpretations from different authors. In a study using European SHARE data, Godard (2016) showed that men tend to increase their BMI after retirement, without changing their levels of physical activity. On the contrary, women tend to increase (albeit not robustly) their leisure time physical activity levels, thus compensating the loss of work-related physical activity and preventing an increase in BMI after retirement. Although his study was also based on a large dataset from a German population, Eibich (2015) found slightly different results: both men and women tend to increase their physical activity after retirement, more than compensating their loss in work-related physical activity leading also to a significant decrease in BMI.

Furthermore, other authors investigated the impact of retirement on grip strength, as predictor for disability and mortality in the elder population (Leong et al., 2015). They reported a short-term positive effect of retirement, but also an increase in the rate of muscle strength loss (Bertoni et al., 2018). Other studies directly investigated mortality and life expectancy, reporting mixed results depending on retirement timing, sex and socioeconomic status (Hallberg et al., 2015; Brockmann et al., 2009; Hult et al., 2010).

The presence of mixed findings in the above-mentioned literature could also be due to the presence of several sources of heterogeneity, which mark differential effects of this transition on health. First, retirement timing (early vs. regular) might be associated with distinct groups and retirement motives, which potentially influence subsequent health and behavior. One study already showed different effects on the considered outcomes depending on this factor (Eibich, 2015). Second, the effect of retirement could be different for men and women. This might be due to the rather selective labor market participation of women especially at older ages, but also to different retirement rules and incentives for both sexes in most countries (US Social Security Administration, 2019). Nevertheless, studies that differentiated for sex, found similar improvements in physical activity in both males and females (Eibich, 2015; Celidoni and Rebba, 2017; Kämpfen and Maurer, 2016; Motegi et al., 2016), but also unclear effects on weight (Eibich, 2015; Godard, 2016; Forman-Hoffman et al., 2008). Third, socioeconomic status might be responsible for differential retirement effects. Most studies that stratified for occupational characteristics found that the positive effect of retirement was stronger for individuals retiring from strenuous occupations (Godard, 2016; Hessel, 2016; Mazzonna and Peracchi, 2015; Kolodziej and Garcia-Gomez, 2019; Shai, 2018; Westerlund et al., 2009) while others found no differential effects (Moon et al., 2012). Additionally, a higher education could also be connected with lower physical occupational strain but also stronger work attachment (Hessel, 2016), representing a source of heterogeneity. Results are however scarce and indicate no heterogeneous effects for different educational groups.

3. Methods

3.1. Data: the KORA survey

We used data from the population-based KORA study (Cooperative Health Research in the Region of Augsburg). We pooled data from two separate surveys, namely S3 (1994–95) and S4 (1999–2000), and the respective follow-up studies [F3 (2004–5), F4 (2006–8), FF4 (2013–14)]. The two baseline surveys were sampled to be population representative, while the loss to follow-up was about 30 %. All participants received a computer-assisted personalized interview (CAPI), several medical examinations, and blood tests. The study was approved by the Ethics Committee of the Bavarian Medical Association (Ethics number: S3 Bundesdatenschutz – F3 03097, S4 99186, F4 and FF4 06068). All study participants gave written informed consent. A detailed description of the KORA study can be found elsewhere (Holle et al., 2005).

For our main model, we focused on individuals who were between 45 and 80 years old. The pooled dataset thus included 11,168 observations, with an average age of 59 years, 49 % males, and 33 % high educated individuals (Table 1).

We analyzed a set of health behaviors, risk factors for chronic disease, and subjective health parameters (Table1). We dichotomized the health behavior variables, including regular physical activity (at least one hour/week)[2], current smoking, no alcohol consumption, and excessive alcohol consumption. The last two variables were calculated based on average self-reported consumption, assessed using a validated recall method (Keil et al., 1997), in which participants were asked how much beer, wine, and spirits they consumed on the previous weekday and weekend. We defined alcohol excess for men (women) as consumption $\geq$24 g/day ($\geq$12 g/day) (Burger et al., 2004).

We analyzed relevant biomedical risk factors for chronic cardiovascular and metabolic disease. These include glycosylated hemoglobin (HbA1c, %), total cholesterol/HDL-cholesterol ratio (CHO/HDL, %), diastolic and systolic blood pressure (mmHg), body-mass-index (BMI, kg/m^2), and waist-to-hip ratio (WHR). All parameters were measured following current standards at the time of data collection. A detailed description of each procedure can be found elsewhere (Laxy et al., 2016; Meisinger et al., 2006; Meisinger et al., 2002). Based on the interquartile range method, severe outliers for each risk factor were identified and excluded from the analysis.

Subjective health status was assessed using the SF12 questionnaire, including a mental and a physical health scale (Ware et al., 1996). Additionally, we assessed self-rated health as a predictor of mortality, especially among the older population (Idler and Benyamini, 1997). The original variable was measured on a 5-point Likert scale from "bad" (1) to "very good" (5) and was dichotomized to indicate "satisfactory health" (score $\geq$3).

Other relevant factors considered were sex, education, living alone, and the intake of antihypertensive medications (AHM). High education was defined as having had at least 12 years of schooling (roughly equivalent to high school). Intake of AHM was determined by a computer-assisted drug recording procedure, involving both self-reported information and drug package collection.

Retirement was defined based on self-reported information. Individuals were considered retired if they reported their current employments status as “retired”. We decided to include in the control group all other employment types, i.e. employed, unemployed, others (homemakers, long-term sick), since according to Nishimura et al. (2018), relevant differences in the effect size across studies investigating the impact of retirement were not due to the sample composition but rather to the methodology applied.

3.2. The German pension system

In Germany, the public pay-as-you-go pension system is still one of the major sources of old age security, although other private and mixed forms are growing in importance (Federal Ministry of Labor and Social Affairs, 2016).

The German pension system offers several alternative pension plans. In Table 2 we provide a brief description of the relevant schemes during the period covered in this study (1994–2014).

In this system, the receipt of a public pension is subject to specific age thresholds. At the age of 65, all individuals with at least 5 years of contributions were entitled to leave their job and receive a full old-age pension, i.e. without deductions in the standard old-age pension plan. Certain subgroups of the population were allowed to retire earlier under alternative schemes, depending on their contribution years and their year of birth (Table 2). At the time of data collection, individuals with a disability, long-term unemployed, partially retired individuals, and women were allowed to retire early at the age of 60 years. Another pension plan allowed long-term insured individuals (with at least 35 years of social security contributions) to retire early with deductions, at the age of 63 (Börsch-Supan et al., 2018; Deutsche Rentenversicherung Bund (DRV), 2019).

In the long period considered, the German pension system underwent some changes. A comprehensive description of the evolution of the system is provided by Börsch-Supan et al. (2018). However, only a small group of individuals surveyed in the last follow-up was affected by these reforms (FF4, 2013–2014). In fact, with the 1999 pension reforms, a stepwise increase in the regular retirement threshold was introduced starting from the year 2012. As the changes in retirement age were very small and progressive, we decided not to control for this issue (Deutsche Rentenversicherung Bund (DRV), 2019). Further modifications in the pension plans during the time period considered are described in Table 2. Most changes involve a stepwise increase of thresholds or a complete deletion of the pension plan. Again, since these modifications were introduced stepwise and regarded only a small group of individuals surveyed in the last follow up, we decided not to control for these issues.

At the time data were collected, most individuals retired either in the standard old-age pension plan at 65 (33 % in 1995 and 42 % in 2013) or in the early retirement plans at age 60 (57 % in 1995 and 37 % in 2012). The other available pension plan (i.e. pension for long-term insured at 63 or 65) was chosen by a smaller number of individuals (Deutsche Rentenversicherung Bund (DRV), 2018).

As depicted in Fig. 1, at the retirement thresholds, the share of retirees increases disproportionately, creating two prominent discontinuities in the probability of retirement, one at 60 years (“early retirement age” – ERA) and one at 65 years (“official retirement age” – ORA). No discontinuity is however visible at 63 years, probably because this pension plan is usually chosen by a relatively small number of individuals (Table 2) (Deutsche Rentenversicherung Bund (DRV), 2018). Additionally, the two discontinuities can be observed for sex and education stratified groups (Appendix A in Supplementary data). Based on these considerations, we exploited the “early” (ERA – retirement at 60) and “official” (ORA – retirement at 65) retirement cutoffs as instruments in our analysis but abstained from considering the retirement age at 63 years as a further cutoff point.

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[2] We adopted the same dichotomization used in other studies (Eibich, 2015; Zhao et al., 2017), in order to increase interpretability and comparability of our results. Nonetheless, we also tested the robustness of our results using the original categorical variables. The direction and significance of the effects did not change.

Table 1
Descriptive statistics of covariates and outcome variables included.

			Not retired		Retired	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Covariates						
Age	11,168	59.28 (8.68)	6,809	54.20 (6.43)	4,359	67.22 (5.00)
Male	11,168	0.49 (0.50)	6,809	0.46 (0.50)	4,359	0.53 (0.50)
High education	11,118	0.33 (0.47)	6,773	0.38 (0.49)	4,345	0.25 (0.43)
Living alone	11,168	0.16 (0.37)	6,809	0.13 (0.33)	4,359	0.22 (0.41)
Antihypertensive med.	11,156	0.31 (0.46)	6,803	0.20 (0.40)	4,353	0.47 (0.50)
Health behavior						
No alcohol	11,155	0.30 (0.46)	6,806	0.28 (0.45)	4,349	0.33 (0.47)
Alcohol excess	11,168	0.32 (0.47)	6,809	0.33 (0.47)	4,359	0.30 (0.46)
Physical activity	11,154	0.49 (0.50)	6,804	0.51 (0.50)	4,350	0.45 (0.50)
Smoking	11,165	0.18 (0.38)	6,809	0.22 (0.41)	4,356	0.12 (0.33)
Risk factors						
HbA1c	10,902	5.53 (0.72)	6,679	5.44 (0.63)	4,223	5.66 (0.82)
BMI	11,083	28.02 (4.50)	6,772	27.61 (4.49)	4,311	28.66 (4.43)
WHR	11,131	0.89 (0.09)	6,790	0.88 (0.09)	4,341	0.91 (0.08)
CHO/HDL ratio	11,024	4.30 (1.43)	6,737	4.24 (1.43)	4,287	4.39 (1.42)
Diastolic BP	11,133	79.93 (11.09)	6,795	80.75 (11.05)	4,338	78.64 (11.05)
Systolic BP	11,146	130.99 (20.38)	6,799	128.07 (19.45)	4,347	135.55 (20.95)
Subjective health						
SF12 mental	7,591	51.48 (9.22)	4,803	51.18 (9.20)	2,788	52.00 (9.25)
SF12 physical	7,591	47.13 (9.04)	4,803	48.49 (8.39)	2,788	44.78 (9.62)
Satisfactory health	10,559	0.84 (0.37)	6,604	0.86 (0.35)	3,955	0.79 (0.41)

Notes: HbA1c (%): glycosylated hemoglobin, BMI (kg/m^2): body mass index, WHR: waist–hip ratio, CHO/HDL ratio: total cholesterol/HDL-cholesterol ratio, BP (mmHg): blood pressure.

Table 2
Overview of the available pension plans in the German pension system in the study period considered (1995-2014).

		Retirement age		Number of retirees (as of 31.12)				Number of new retirees (whole year)			
	Min. yrs of contribution	ERA	ORA	1995		2013		1995		2013	
Standard old-age pension[a]	5		65	10,165,298	(76 %)	8,039,899	(46 %)	327,781	(33 %)	274,082	(42 %)
Pension for long-term insured[b]	35	63	65	539,991	(4%)	1,564,978	(9%)	97,516	(10 %)	114,023	(18 %)
Pension for especially long-term insured[c]	45		63	–		28,860	(0.2 %)			16,197	(2%)
Pension for women[d]	15	60	65	1,202,343	(9%)	3,856,264	(22 %)	233,832	(23 %)	97,680	(15 %)
Pension for long-term unemployed/partial retirement[e]	15	60	65	872,915	(7%)	2,388,958	(14 %)	294,133	(29 %)	66,703	(10 %)
Pension for severely disabled[f]	35	60	63	554,010	(4%)	1,777,289	(10 %)	47,563	(5%)	79,484	(12 %)
Total				13,334,557		17,656,248		1,000,825		648,169	

[a] With the 1999 pension reforms, the official retirement age was increased stepwise from 65 to 67 for individuals born between 1947–1964. These changes started in 2012. As such they affected a small group of individuals surveyed in the last follow-up included (FF4 - 2013/2014).

[b] For individuals born 1949–1963 the official retirement age threshold was increased stepwise from 65 to 67, starting from 2012. This change is only relevant for a small group of individuals surveyed in the last follow-up (FF4 - 2013/2014). The early retirement threshold for this group remained constant and is connected with deductions.

[c] This type of pension was introduced in 2013. For individuals born from 1953 to 1964, the age threshold is increased stepwise from 63 to 65. Early retirement with deductions is not possible under this plan. This change is only relevant for individuals surveyed in the last study (FF4 - 2013/2014).

[d] Women born between 1940–1951 were allowed to retire early with deductions from their final pension. Early retirement for women was eliminated for individuals born 1952 onwards: this change is only relevant for individuals in the last included study (FF4 - 2013/2014). Starting from 1999 (birth cohorts 1940–1944) the ORA threshold was increased stepwise from 60 to 65.

[e] Individuals born 1936–1945 could retire early with deductions. For individuals born 1946–1948 the ERA was raised stepwise from 60 to 63. This type of pension was eliminated for individuals born 1952 onwards. These changes are only relevant for individuals surveyed in the last included study (FF4 - 2013/2014). Starting from 1996 (birth cohorts 1937–1941) the ORA threshold was increased stepwise from 60 to 65.

[f] For individuals born 1952–1964, a stepwise increase of the ERA to 62 years was introduced. This change is only relevant for individuals surveyed in the last study (FF4 - 2013/2014). Starting from 2000 (birth cohorts 1941–1943) the ORA threshold was increased stepwise from 60 to 63.Sources: Börsch-Supan et al. (2018),Idler and Benyamini (1997), Federal Ministry of Labor and Social Affairs (2016); Deutsche Rentenversicherung Bund (DRV) (2019), Deutsche Rentenversicherung Bund (DRV) (2018); own modification based on Eibich (2015).

3.3. RDD rationale and identification strategy

In order to estimate the causal effect of retirement, we used a regression discontinuity design (RDD). This method has already been widely used in health economics in previous studies of retirement and health (Coe and Zamarro, 2011; Eibich, 2015; Godard, 2016; Insler, 2014; Johnston and Lee, 2009; Müller and Shaikh, 2018; Zhao et al., 2017).

RDD can be applied when treatment is determined by whether a continuous "assignment variable" exceeds an exogenously determined threshold. If the assignment variable is not manipulable by individuals and if pretreatment covariates are continuous around the threshold, the exogenous assignment rule creates a local randomization in the treatment status and in the covariates around the threshold (Lee and Lemieux, 2010; Bor et al., 2014). As a result, individuals just below the threshold can be considered as a

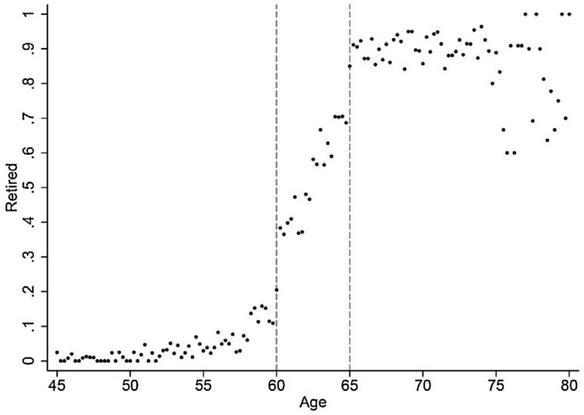

Fig. 1. Share of retirees by age group (bins of 3 months).
Note: each dot represents the share of retired individuals in age groups of 3 months. The drop in the share of retirees after 75 years is due to a decrease in the number of observations, so that each age quarter consists of only a few individuals. If, among these few, a couple are classified as others or are still working, this would have a big impact on the share of retirees computed for those age quarters.

valid control group for those just above the threshold, allowing valid estimation of causal treatment effects.

In our case, as treatment (retirement) is assigned probabilistically, the average treatment effect must be scaled by the difference in the probability of obtaining treatment at the threshold or, in other words, by the discontinuity in the treatment ("fuzzy" RDD) (Lee and Lemieux, 2010). This amounts to estimating a local average treatment effect (LATE) for compliers, i.e., those individuals whose treatment assignment would change with the instrument (Lee and Lemieux, 2010). This effect can be estimated using a Wald estimator, using the exogenous threshold as instrumental variables (IVs), in a two-stage least squares model (Lee and Lemieux, 2010; Bor et al., 2014). For the main specification, we included both thresholds simultaneously as IVs. As the compliers are likely to be different for both cutoffs, we also estimated separate models for ERA (60) and ORA (65) thresholds. In the main model, we estimated the following equations:

$$r_{it} = \gamma_0 + \gamma_1 f(age)_{it} + \delta_1 ERA_{it} + \delta_2 ORA_{it} + u_{it} \tag{1}$$

$$health_{it} = \beta_0 + \beta_1 f(age)_{it} + \tau_1 \widehat{r}_{it} + \varepsilon_{it} \tag{2}$$

In the first stage (Eq. 1), we regressed the retirement status on a function of age and two binary variables taking on value 1 if the individual i is above the retirement thresholds at 60 (ERA) or 65 (ORA), and 0 otherwise. In the second stage (Eq. 2), we regressed the outcomes on a function of age and the estimated retirement status from the first stage.

Owing to limited sample size, we adopted a parametric regression including the whole sample of observations (from 45 to 80 years old for the main model, i.e., adopting a bandwidth of 15 years on both sides of each cutoff) (Lee and Lemieux, 2010; Moscoe et al., 2015). A parametric approach offers the advantage of using more data in the estimation, and thus provides more precise estimates (Lee and Lemieux, 2010). Since also data far away from the cutoff are used, the challenge of a parametric estimation is the correct modeling of the health–age relationship around the cutoff, in order to exclude the possibility that eventual non-linearities are mistaken for the effect of treatment (Lee and Lemieux, 2010; Angrist and Pischke, 2008). To evaluate the age specification that best fitted our data, we used the Akaike Information Criterion (AIC) (Lee and Lemieux, 2010), comparing specifications with age polynomials up to the second degree (linear and quadratic). Following the suggestion by Burnham and Anderson (2004), the simpler linear specification was preferred, unless the more complex quadratic specification was better by more than 10 points ($\Delta_{AIC} > 10$) (Burnham and Anderson, 2004). For the complete analysis, see Appendix B in Supplementary data.

Despite dealing with panel data, we decided not to include individual-specific fixed effects. In fact, according to Lee and Lemieux (2010), the inclusion of individual-specific fixed effects is not necessary for the identification in a regression discontinuity design. Furthermore, including fixed effects would have caused a loss of observations due to panel attrition. Panel attrition might have been caused by several reasons, among others health deterioration or a direct retirement effect, but also moving away from the area of Augsburg or other reasons not related to employment or health (e.g. care of relatives). To test for the effects of panel attrition we carried out a sensitivity check including only individuals who are present in the sample at least two times.

In a further step, we investigated heterogeneous effects stratifying by sex and educational level. All analyses were performed using STATA 14 (Stata Corporation, College Station, TX, USA).

Since we were conducting multiple estimations to investigate the effect of retirement on a large number of parameters, concerns regarding type I errors due to multiple testing could arise. To control for this issue, we reported corrected significance levels based on p-values following a stepdown correction procedure (Romano and Wolf, 2016; Clarke, 2018). Effects were considered significant if they showed a p-value<0.05.

All assumptions for a valid estimation with regression discontinuity design were satisfied. The assignment variable (age) was continuous around the cutoff and by construction was not manipulable by individuals (see Appendix C in Supplementary data). Furthermore, we carried out a graphical analysis of potentially relevant predetermined covariates in the dataset (male, education, living alone) to test their continuity around the cutoff. If they were not continuous, doubts regarding the causal interpretability of estimates may arise (Lee and Lemieux, 2010). However, in our sample the variables investigated were comparable on both sides of the cutoffs (Appendix D in Supplementary data). The analysis for AHM revealed a positive discontinuity in this factor at retirement. Hence, the results for diastolic and systolic blood pressure should be interpreted with caution (Appendix E in Supplementary data).

Visual analysis of the outcomes revealed a discontinuity in both ERA and ORA cutoffs. However, results were strongly dependent on the outcome considered (Appendix D in Supplementary data).

4. Results

Results of the first-stage regression (Table 3) showed that both ERA and ORA instruments are highly significant and have a positive effect on the retirement probability. Hence, the relevance assumption of IV regression was satisfied and the age thresholds can be used as relevant instruments.

The main results are reported in Table 4. All models showed a Kleibergen–Paap Wald F-statistic (Fstat) larger than the cutoff value of 10 for validity of the instruments (Staiger and Stock, 1994). This indicates that the instruments were not weak in all models. Furthermore, instruments in the official retirement models (ORA) were weaker than instruments in the early and combined models. Results of the Sargan-Hansen overidentification test could not reject the null hypothesis that the instruments are jointly valid, also indicating no heterogeneity between the two instruments. Nevertheless, the institutional setting suggests that heterogeneous effects are plausible, and we therefore carried out a stratified analysis.

Table 3
First-stage results.

	linear			quadratic		
	Both	ERA	ORA	Both	ERA	ORA
ERA	0.413***	0.397***		0.41***	0.385***	
	(0.014)	(0.014)		(0.013)	(0.014)	
ORA	0.323***		0.252***	0.346***		0.329***
	(0.013)		(0.016)	(0.015)		(0.015)
Age	0.007***	0.022***	0.035***	(0.026)***	−0.083***	0.201***
	(0.001)	(0.001)	(0.001)	0.005	(0.005)	(0.008)
Age^2				0.000***	0.001***	−0.001***
				(0.000)	(0.000)	(0.000)
N	11,168	10,935	9,290	11,168	10,935	9,290
R^2	0.618	0.589	0.52	0.618	0.603	0.539

Notes: Fuzzy regression discontinuity design first-stage coefficients. 95 % confidence intervals in brackets. Both: model including both cutoffs as instruments; ERA: model including only the early retirement cutoff (60) as instrument; ORA: model including only the regular retirement cutoff (65) as instrument. Significance: * $p < .05$; ** $p < .01$; ***$p < .001$.

Table 4
Fuzzy regression discontinuity analysis results.

	Both				ERA			ORA		
	Effect (SE)	N	Fstat	Hansen	*Effect (SE)*	N	Fstat	*Effect (SE)*	N	Fstat
Health behavior										
Alcohol excess	−0.010	11,168	1,591	0.059	0.039	10,935	699	−0.053	9,290	242
	(0.028)				(0.04)			(0.066)		
No alcohol	0.040	11,155	1,589	0.691	0.038	10,922	697	0.008	9,279	243
	(0.027)				(0.039)			(0.065)		
Physical activity	0.046	11,154	1,589	0.065	0.125**	10,921	696	−0.009	9,279	244
	(0.031)				(0.044)			(0.071)		
Smoking	−0.027	11,165	1,591	0.827	−0.023	10,932	698	−0.034	9,287	243
	(0.022)				(0.031)			(0.047)		
Risk factors										
HbA1c	−0.020	10,902	1,567	0.386	0.005	10,670	683	0.001	9,047	395
	(0.044)				(0.064)			(0.093)		
CHO/HDL	**0.280*****	11,024	1,245	0.094	0.014	10,792	649	**0.471****	9,165	404
	(0.085)				(0.125)			(0.159)		
BMI	0.640**	11,083	1,262	0.191	**1.111****	10,851	670	0.125	9,211	397
	(0.248)				(0.352)			(0.488)		
WHR	0.001	11,131	1,262	0.029	0.014*	10,900	672	−0.015	9,255	400
	(0.005)				(0.007)			(0.009)		
Diastolic BP	**2.102****	11,133	1,255	0.209	0.408	10,904	666	0.325	9,258	242
	(0.673)				(0.973)			(1.557)		
Systolic BP	**5.647*****	11,146	1,259	0.052	−0.513	10,914	698	4.962	9,270	242
	(1.263)				(1.708)			(2.948)		
Subjective health										
SF12 mental	1.175	7,591	1,258	0.087	1.990	7,392	470	−0.078	6,208	234
	(0.687)				(1.032)			(1.362)		
SF12 physical	1.594*	7,591	1,258	0.527	1.412	7,392	470	2.310*	6,208	353
	(0.66)				(1.015)			(1.15)		
Satisfactory health	0.079*	10,559	953	0.452	0.064	10,552	665	0.108	8,713	250
	(0.031)				(0.035)			(0.059)		

Notes: Fuzzy regression discontinuity design second-stage coefficients. Cluster-robust standard errors in parentheses. Both: model including both cutoffs as instruments; ERA: model including only the early retirement cutoff (60) as instrument; ORA: model including only the regular retirement cutoff (65) as instrument. HbA1c (%): glycosylated hemoglobin, CHO/HDL ratio: total cholesterol/HDL-cholesterol ratio, BMI (kg/m^2): body-mass-index, WHR: waist–hip ratio, BP (mmHg): blood pressure. Choice of the age polynomial (linear or quadratic) was based on the Akaike-Information Criterion (AIC) (Appendix B in Supplementary data), only the results of the preferred specification are

The results indicated no significant impact of retirement on alcohol consumption and smoking. In contrast, retirement increased the probability of regular physical activity in the early retirees by more than 10 percentage points ($p < 0.01$). This effect was however not significant anymore after correcting the p-value for multiple testing. The effects for the general and ORA models also showed positive coefficients, but with large confidence intervals (Table 4).

Some biomedical risk factors showed a significant worsening after retirement, which were in most cases robust to p-value corrections. In the general population, retirement led to an increase in CHO/HDL and BMI. Regular retirees showed a strong increase in CHO/HDL (corrected $p < 0.01$). Early retirees (ERA) showed a strong increase in BMI (corrected $p < 0.01$), alongside with an increase in WHR (Table 4). Furthermore, the analysis showed an increase in diastolic and systolic blood pressure after retirement (corrected $p < 0.01$). However, this result should be interpreted with caution, not only because the assumptions testing revealed a parallel increase in AHM intake (Appendix E in Supplementary data), but also due to the weaker and non-significant coefficients highlighted in the separate analyses for ERA and ORA reported in Table 4.

The effect on subjective mental health (SF12 mental) showed positive, albeit not significant coefficients for all groups

Table 5
Fuzzy regression discontinuity analysis results for sex groups.

	Male			Female		
	Both	ERA	ORA	Both	ERA	ORA
Health behavior						
Alcohol excess	−0.054	0.041	−0.116	0.028	0.023	0.043
	(0.043)	(0.06)	(0.086)	(0.037)	(0.053)	(0.066)
No alcohol	0.078*	0.076	0.098	0.021	0.031	−0.017
	(0.032)	(0.046)	(0.086)	(0.042)	(0.06)	(0.076)
Physical activity	0.086	0.122*	0.122	0.006	0.129*	−0.091
	(0.045)	(0.062)	(0.115)	(0.043)	(0.062)	(0.076)
Smoking	−0.045	−0.053	−0.019	−0.014	−0.001	−0.040
	(0.034)	(0.048)	(0.080)	(0.028)	(0.040)	(0.055)
Risk factors						
HbA1c	−0.090	−0.049	−0.147	0.053	0.061	0.096
	(0.067)	(0.099)	(0.145)	(0.059)	(0.082)	(0.143)
CHO/HDL	0.279*	−0.244	0.729*	0.232*	0.185	0.082
	(0.128)	(0.182)	(0.312)	(0.107)	(0.158)	(0.195)
BMI	0.067	0.730	−0.330	0.822*	1.514**	0.058
	(0.306)	(0.439)	(0.783)	(0.381)	(0.555)	(0.733)
WHR	−0.007	0.000	−0.013	−0.002	0.014	−0.018
	(0.005)	(0.007)	(0.010)	(0.005)	(0.007)	(0.009)
Diastolic BP	1.505	0.114	3.356	2.428**	0.217	1.192
	(0.976)	(1.391)	(1.919)	(0.914)	(1.317)	(1.946)
Systolic BP	4.933**	0.512	1.954	2.464	−2.237	8.150*
	(1.759)	(2.364)	(4.586)	(1.705)	(2.402)	(3.838)
Subjective health						
SF12 mental	1.467	1.692	2.036	0.870	2.235	−1.703
	(0.922)	(1.431)	(1.827)	(1.008)	(1.474)	(1.974)
SF12 physical	1.490	0.478	3.117	1.664	2.256	1.795
	(0.946)	(1.466)	(1.668)	(0.922)	(1.404)	(1.855)
Satisfactory health	0.076	0.046	0.147	0.062	0.072	0.068
	(0.044)	(0.052)	(0.087)	(0.036)	(0.048)	(0.085)

Notes: Fuzzy regression discontinuity design second-stage coefficients. Cluster-robust standard errors in parentheses. Both: model including both cutoffs as instruments; ERA: model including only the early retirement cutoff (60) as instrument; ORA: model including only the regular retirement cutoff (65) as instrument. HbA1c (%): glycosylated hemoglobin, CHO/HDL ratio: total cholesterol/HDL-cholesterol ratio, BMI (kg/m^2): body-mass-index, WHR: waist–hip ratio, BP (mmHg): blood pressure. Choice of the age polynomial (linear or quadratic) was based on the Akaike-Information Criterion (AIC), only the results of the preferred specification are reported here. Fstat: Kleibergen-Paap Wald F-statistic. Significance: * $p < .05$; ** $p < .01$; *** $p < .001$; no results were significant after Romano-Wolf correction for multiple testing.

considered. The effect on subjective physical health (SF12 physical) was positive and significant, but not robust to p-value corrections. The same positive result can be observed for self-rated health. After retirement, participants were more likely to report at least satisfactory health (Table 4).

4.1. Heterogeneity

The sex-stratified analysis is shown in Table 5. In the pooled analysis, we observed increases in CHO/HDL, BMI and diastolic blood pressure for women. Furthermore, females who retired early improved their physical activity significantly, but at the same time, they presented also a significant increase in BMI. Men tended to improve their health behavior after retirement (eg. significantly higher frequency of no alcohol consumption and higher physical activity), but with large confidence intervals for most parameters. They also showed an increase in systolic blood pressure and CHO/HDL. The latter was especially present in regular retirees.

Regarding subjective health, we observed increasing albeit non-significant trends in both groups. The only exception was subjective mental health in women retiring regularly, for which large negative effects cannot be ruled out.

The analysis stratified by educational level is reported in Table 6. In the pooled analysis, low educated individuals showed increased CHO/HDL, BMI and diastolic blood pressure. Furthermore, low educated individuals retiring early significantly increased their physical activity after retirement, but also revealed significant increases in BMI and WHR.

Additionally, low educated individuals also presented significant increases in subjective physical health and satisfactory health. In contrast, high educated individuals did not show any significant effect of retirement, except a non-robust increase in systolic blood pressure in the general population.

Romano-Wolf p-value corrections showed however that only the increase in physical activity and systolic blood pressure in the low educated group are robust results, while none of the other coefficients are robust to correction for multiple testing. Despite some notable differences in the sign as well as the magnitude of the point estimate, due to the small sample sizes for the subgroups the differences between men and women and high and low educated individuals were never significant.

4.2. Robustness checks

We tested the robustness of our results, as suggested by different guidelines, using both a specification curve, in which we plotted estimates for linear and quadratic specification coefficients for different successively declining bandwidths (15, 12, 10, 7 and 5 years around the cutoffs), and a sensitivity analysis table (Appendix F, Table F.1 in Supplementary data) (Lee and Lemieux, 2010; Bor et al., 2014; Moscoe et al., 2015; Christensen and Miguel, 2018; Simonsohn et al., 2015). In Figs. 2–4 we presented examples of specification curves for selected outcomes and models.

The visual inspection of the curves showed robust results for almost all outcomes for different bandwidth and polynomial choices (Appendix F, Table F.1 in Supplementary data). Obviously, confidence intervals generally increased with decreasing bandwidth. Furthermore, most non-significant results from the main analysis still showed large confidence intervals, in some cases with volatile point estimates including opposite values (e.g. smoking,

Table 6
Fuzzy regression discontinuity analysis results for educational groups.

	Low education			High education		
	Both	ERA	ORA	Both	ERA	ORA
Health behavior						
Alcohol excess	0.002	0.018	−0.013	−0.040	0.104	−0.086
	(0.034)	(0.045)	(0.096)	(0.049)	(0.088)	(0.085)
No alcohol	0.033	0.024	0.005	0.049	0.076	0.010
	(0.035)	(0.046)	(0.100)	(0.041)	(0.074)	(0.073)
Physical activity	0.073	**0.170*****	−0.044	0.023	0.013	0.113
	(0.038)	(0.05)	(0.079)	(0.052)	(0.09)	(0.089)
Smoking	−0.020	−0.013	−0.066	−0.039	−0.062	0.017
	(0.027)	(0.036)	(0.072)	(0.036)	(0.062)	(0.055)
Risk factors						
HbA1c	−0.042	0.002	−0.080	0.046	0.001	0.099
	(0.058)	(0.079)	(0.137)	(0.064)	(0.109)	(0.117)
CHO/HDL	0.261**	0.043	0.449*	0.294	−0.097	0.154
	(0.101)	(0.137)	(0.221)	(0.159)	(0.312)	(0.241)
BMI	0.665*	0.974*	0.292	0.366	0.709	−0.233
	(0.295)	(0.39)	(0.696)	(0.454)	(0.677)	(0.629)
WHR	0.006	0.016*	−0.011	−0.005	0.002	−0.015
	(0.006)	(0.007)	(0.013)	(0.008)	(0.013)	(0.012)
Diastolic BP	2.074**	0.421	1.224	2.291	1.002	2.466
	(0.803)	(1.057)	(2.326)	(1.234)	(2.546)	(1.709)
Systolic BP	**5.244*****	−0.493	7.277	5.581*	−0.334	5.723
	(1.514)	(1.957)	(4.466)	(2.285)	(3.545)	(3.208)
Subjective health						
SF12 mental	1.654	2.325	−0.193	0.896	1.715	0.464
	(0.883)	(1.260)	(2.016)	(1.059)	(1.874)	(1.676)
SF12 physical	2.257**	1.974	3.030	0.529	1.207	1.214
	(0.860)	(1.247)	(1.609)	(1.008)	(1.769)	(1.741)
Satisfactory health	0.079*	0.053	0.142	0.064	0.104	0.030
	(0.036)	(0.041)	(0.081)	(0.038)	(0.066)	(0.082)

Notes: Fuzzy regression discontinuity design second-stage coefficients. Cluster-robust standard errors in parentheses. Both: model including both cutoffs as instruments; ERA: model including only the early retirement cutoff (60) as instrument; ORA: model including only the regular retirement cutoff (65) as instrument. HbA1c (%): glycosylated hemoglobin, CHO/HDL ratio: total cholesterol/HDL-cholesterol ratio, BMI (kg/m^2): body-mass-index, WHR: waist–hip ratio, BP (mmHg): blood pressure. Choice of the age polynomial (linear or quadratic) was based on the Akaike-Information Criterion (AIC), only the results of the preferred specification are reported here. Fstat: Kleibergen-Paap Wald F-statistic. Significance: * $p < .05$; ** $p < .01$; *** $p < .001$; in bold: significant coefficients after Romano-Wolf correction for multiple testing.

HbA1c). However, for the effects of retirement on physical activity, CHO/HDL, BMI, WHR, and subjective health, which were already found to be significant in the main analysis, the curves confirmed positive effects, with strongly robust point estimates to alternative bandwidth choices (Fig. 2). Finally, the results for blood pressure parameters showed much volatility of the effect and large confidence intervals mostly including the zero (Fig. 3). For this reason, no robust effect of retirement on these parameters could be determined for the overall population.

For the sex-stratified analysis, the specification curves confirmed the robustness of our results for physical activity, CHO/HDL, BMI, WHR and subjective health (Appendix G, Table G.1–2 in Supplementary data). They also helped to shed light on effect estimates for CHO/HDL in the pooled analysis (Fig. 4). As emerged from the graphs, this factor was strongly dependent on sex and timing: men who retired early showed a decrease while men who retired regularly showed a robust increase in CHO/HDL. The opposite was true for women (Fig. 4). Also, in the sex-stratified analysis, the curves revealed that the effects on blood pressure parameters are not robust to different modeling choices and should thus be interpreted with caution. Finally, the curves pointed towards another interesting result regarding HbA1c levels: independently from retirement timing, women showed mostly increasing effects, while men showed mostly decreasing effects of retirement on this factor. Although the confidence intervals were very large, they mainly stretched in one direction, excluding the possibility of very large opposite effects.

Specification curves for the stratification by educational level largely confirmed the results of the main analysis (Appendix H, Table H.1-2 in Supplementary data). The only exceptions concern again systolic blood pressure, whose coefficients were very volatile depending on modelling choices. Instead, the effect on diastolic blood pressure in low educated individuals was increasing and robust with respect to almost all specifications considered.

Furthermore, we carried out additional robustness checks. First, we ran the same analysis focusing only on employed or self-employed and retired individuals. In this way we excluded some observations which could potentially attenuate the effect, since for the excluded group the change from non-retired to retired should have fewer consequences. By observing results tables in Appendix I (in Supplementary data), we see that the point estimates largely confirm the results of the main analysis. Standard errors on all parameters increase due to a decrease in sample size, leading thus to a loss in significance for some parameters. For women and low educated we observe a general increase in the parameter estimates, with coefficients significantly different from zero and, thereby, confirming the results highlighted in the main analysis despite a decrease in sample size. This is probably due to the fact that the excluded group included a large share of women and low educated individuals (share of male is now 56 % instead of 49 % as in the main analysis) and indicates that the results of the main analysis should be interpreted as lower bounds of the true underlying effect.

As the exogenously determined cutoffs create a local randomization, there is no need to adjust for potential confounders (Lee and Lemieux, 2010; Calonico et al., 2020). Nevertheless, we ran a robustness check, comparing models with and without covariates (male, education, month, and year fixed effects) (Appendix J in Supplementary data). The curves showed slightly different point estimates, but generally confirmed the results of the main analysis.

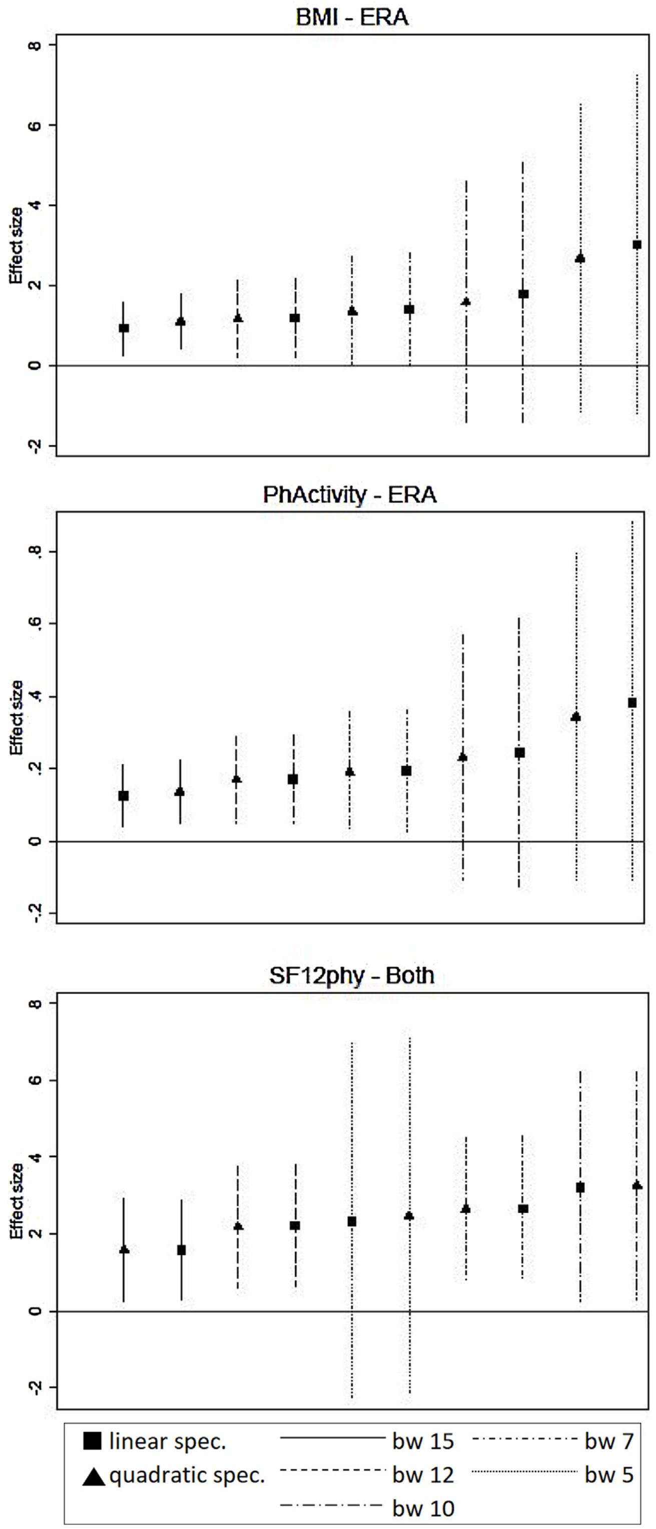

Fig. 2. Selected specification curves.
Note: the full set of specification curves for all outcomes is available in Appendix F (in Supplementary data). Bw: bandwidth. BMI (kg/m^2): body-mass-index. PhActivity: physical activity. SF12phy: subjective physical health. Both: model including both cutoffs as instruments; ERA: ealy retirement age.

Additionally, the dataset we investigated presented a relatively low dropout rate between the follow-ups (30 %). However, if the dropouts are not missing at random, as assumed in the main estimation, loss to follow-up could cause selection bias issues. Therefore, we tested robustness by including only individuals for whom at least two observations were available (Appendix K in Supplementary data). Also, these curves generally confirmed the results of the main analysis.

Furthermore, as higher order polynomials or age–cutoff interactions would likely cause an over-specification of the model, we decided to limit our model selection to continuous linear and quadratic specifications. However, we extensively tested the robustness of our results using higher order polynomials or age-cutoff interactions (Appendix L–M in Supplementary data). Results showed larger confidence intervals, but point estimates generally confirmed the results of the main analysis. In some cases, results from the age-cutoff interactions models showed a much higher volatility of point estimates with some very large effects. These results confirmed our assumption that higher order polynomials and age-cutoff interactions are very likely to overfit our model and are thus not suitable to be considered as main specifications.

5. Discussion

The study results show that retirement leads to an increase in BMI and CHO/HDL levels. These might be accompanied by increases in WHR and blood pressure, but at the same time also by positive effects on physical activity and subjective physical health. While the effect on subjective health is similar in all models considered, the effect on health behavior and biomedical risk factors strongly depends on retirement timing and sex, and thus on the underlying population of compliers considered. This is not surprising as the two retirement thresholds mark two different exit routes (Deutsche Rentenversicherung Bund (DRV), 2019; Gruber and Wise, 2008).

Results indicate that individuals retiring regularly (at the age 65 years cutoff) benefit from retirement especially on a subjective level, as their subjective physical health increases with retirement. This probably results from a relief in work-related stress and fatigue symptoms, as other authors have already shown (Mazzonna and Peracchi, 2015; Westerlund et al., 2010). In contrast, most risk factors and health behaviors did not display any robust change, implying that, for most regular retirees, retirement represents a smooth transition regarding the considered parameters. In this group, no significant differences between men and women, high and low educated individuals could be highlighted. The only exception is a significant increase in CHO/HDL, especially for regular male retirees. Interestingly, this result is robust to multiple testing p-value corrections and several sensitivity analyses, including different bandwidth choices.

At the early retirement threshold, only individuals with a disability, long-term unemployed, partially retired individuals, and women were allowed to retire early (Deutsche Rentenversicherung Bund (DRV), 2019). Results show positive effects of early retirement on physical activity, together with a strong increase in BMI and WHR. Other risk factors, such as CHO/HDL or systolic blood pressure, display consistently worsening coefficients, indicating that, if an effect of retirement on these factors exists, it is likely to be small and deleterious.

In the case of early retirees, however, the results of the stratified analysis might be more informative. In fact, in this group, the characteristics of the underlying complier population and the retirement reasons might be strongly related to sex, as women were allowed to retire early, while men were allowed to retire early only if they had a disability or were long-term unemployed or in partial retirement (Deutsche Rentenversicherung Bund (DRV), 2019). For men retiring early, health-related reasons might play an important role in the decision to retire, much more so than for their female counterparts. However, when comparing results for male and female retirees, it should be noted that labor market

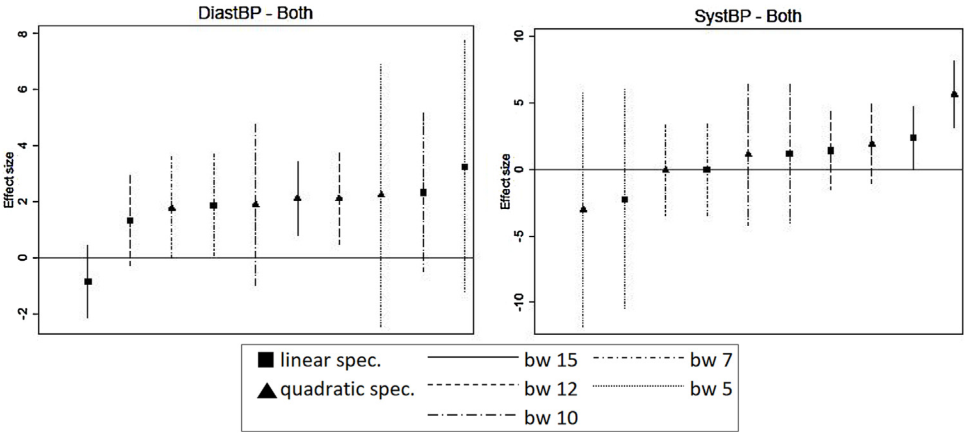

Fig. 3. Selected specification curves.
Note: the full set of specification curves for all outcomes is available in Appendix F (in Supplementary data). Bw: bandwidth. DiastBP (mmHg): diastolic blood pressure; SystBP (mmHg): systolic blood pressure.

participation of older women is more selective than participation of older men. At the time the data were collected, women had a lower labor market participation before retirement than men and those who worked were more likely to be high educated (Börsch-Supan and Ferrari, 2017; OECD, 2020). This does not threaten the internal validity of our RDD estimator. However, it implies that the local average treatment effect estimated in the RDD model applies to a specific subgroup, and it cannot be generalized to the overall population of women. Results from the sensitivity analysis focusing only on employed and retired individuals confirmed that the results in the main analysis can be interpreted as a lower bound of the true underlying effect for women retiring directly from employment. However, based on our data we could not investigate how specific work characteristics (such as work-related physical activity, job strain, job satisfaction), which might be responsible for a higher occupational selection in women, generate heterogeneity in the results.

Our analysis indicates that, for men retiring early, retirement marks a positive transition, leading to a significant increase in physical activity. Risk factors show no effect or generally negative coefficients, with confidence intervals mainly stretching on the negative side, supporting the hypothesis of a positive effect of retirement in this group. For women, the same increase in physical activity could be observed. However, this is also accompanied by a significant increase in BMI, WHR, and increasing trends on CHO/HDL and HbA1c. The same result of increasing physical activity alongside increasing BMI and WHR was observed also for low educated individuals who retired early. It has to be remarked that these results are robust to different model specifications, but after correction for multiple testing, only the increase in BMI in the ERA population remains significant. One could speculate on the link between these results, which leads to interesting potential interpretations regarding the mechanisms of retirement on health for the group of early female and low educated retirees. In fact, our results might indicate that in women and low educated individuals who retire early the increase in leisure time physical activity is probably not enough to compensate for the decrease in work-related activity, as BMI and WHR tend to increase. Other authors suggested similar compensation mechanism between physical activity and BMI, albeit with different results (Zantinge et al., 2013; Goldman et al., 2008). Other possible mechanisms, such as changes in dietary and sleep patterns, found only selective support in previous studies (Eibich, 2015; Goldman et al., 2008). For low educated individuals this result is not surprising, since they are more likely to retire from physically demanding occupations than high educated individuals. Despite a general relief from occupational strain, which is reflected in the increase in subjective physical health, working seemed to have had a protective effect on their BMI and WHR. For women the interpretation of this result is less clear and should be further investigated, as their labor market participation is more selective in terms of occupation than men. Besides potential interpretations and links between the parameters observed, these findings suggest that early female retirees and retirees with low education should be considered as high-risk groups for a negative effect of retirement on biomedical risk factors, which could in turn affect their long-run risk of cardiovascular and metabolic disease.

The effects we found are also interesting in light of previous research. Godard (2016) reveals in fact that women tend to increase their physical activity after retirement. However, women also showed no significant changes in BMI. The author thus suggested that women are able to fully compensate for the loss of work-related physical activity by increasing their leisure time physical activity after retirement. The study of Eibich, based on German Socio-Economic Panel (SOEP) data, projected a different scenario: both men and women tend to increase their physical activity and decrease their BMI after retirement. In this case thus, it seems that both groups are able to more than compensate their loss of work-related physical activity (Eibich, 2015). This comparison with the literature highlights more than any other result the complexity and strong heterogeneity of the effects of retirement and its potential underlying mechanisms. We strongly encourage further research, especially aiming at including further determinants of BMI, such as diet and sleep patterns.

The results for blood pressure show a detrimental effect of retirement on both systolic and diastolic pressure. However, these results should be interpreted with caution, not only because of the poor robustness of the effects to different specifications and bandwidths but also because of the increased AHM intake upon retirement. The effect might thus be downward biased, hampering the clear identification of the effect of retirement on blood pressure. However, increasing blood pressure despite increasing AHM intake corroborates the result that retirement might have a deleterious effect on this parameter. Further analysis is needed to establish the direction of causality and the presence of unobserved confounders (e.g., more frequent doctor visits).

The results from the analysis of health behaviors are generally in line with previous literature. The role of retirement on alcohol

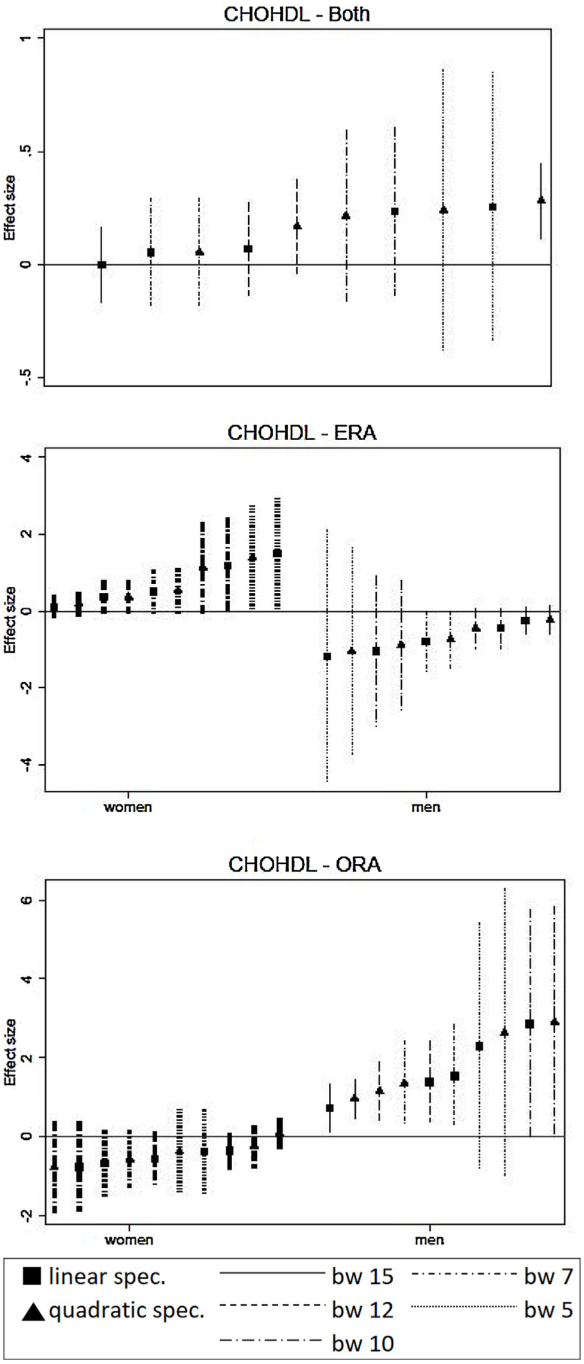

Fig. 4. Selected specification curves – stratification.
Note: the full set of specification curves for all outcomes is available in Appendix F & G (in Supplementary data). Bw: bandwidth. ERA: early retirement age. ORA: official retirement age.

consumption is ambiguous and, as our study also shows, depends on the indicator used and on the group considered (Eibich, 2015; Müller and Shaikh, 2018; Zhao et al., 2017; Celidoni and Rebba, 2017; Motegi et al., 2016; Zhu, 2016). The effect on smoking, albeit non-significant, is also comparable with previous findings, which show that retirement causes a reduction in smoking probability by a few percentage points in the overall population (Eibich, 2015; Insler, 2014; Zhao et al., 2017; Celidoni and Rebba, 2017; Kämpfen and Maurer, 2016; Zhu, 2016). The increase in physical activity, in both men and women, is generally in line with previous research (Eibich, 2015; Insler, 2014; Müller and Shaikh, 2018; Zhao et al., 2017; Celidoni and Rebba, 2017; Kämpfen and Maurer, 2016; Motegi et al., 2016; Zhu, 2016). However, the only study differentiating the analysis for early and regular retirees, also based on German data, showed that the increase in physical activity is actually driven by the regular retirees and not by the early retirees group (Eibich, 2015).

Our study corroborates the evidence that retirement leads to an increase in BMI in the early-retired population, in line with the increase in WHR. No effect was shown for regular retirees. The available evidence regarding BMI is ambiguous: the majority of studies report an increase in BMI, but some report negative or null effects (Eibich, 2015; Godard, 2016; Johnston and Lee, 2009; Behncke, 2012; Chung et al., 2009), with different but mixed effects between timing, sex, and education (Eibich, 2015; Godard, 2016; Hessel, 2016; Forman-Hoffman et al., 2008). As BMI marks a very important risk factor for chronic disease, this heterogeneity should be investigated further. Regarding the other risk factors considered, few comparable studies are available. Behncke (2012) showed a similar worsening of metabolic syndrome symptoms as aggregated parameter including cholesterol levels and blood pressure. However, she used a different methodology, which leaves open concerns of potential residual bias.

The same increasing trend in self-assessed health upon retirement was reported in most previous studies (Coe and Zamarro, 2011; Eibich, 2015; Johnston and Lee, 2009; Oshio and Kan, 2017; Zhu, 2016; Blake and Garrouste, 2013; Hessel, 2016; Mazzonna and Peracchi, 2015; Neuman, 2007) with a few exceptions (Johnston and Lee, 2009; Sahlgren, 2012; Dave et al., 2006).

Basing our analysis on epidemiological data gave us the opportunity to investigate simultaneously the effect of retirement on objectively measured biomedical risk factors for chronic disease, self-reported health behavior, and subjective health indicators, allowing the identification of possible mechanisms. The methodology we used enabled us to estimate the causal effect of retirement, taking the problem of unmeasured confounding and reverse causation into account. However, the study presented some limitations, mainly related to a limited sample size. First, although we used the whole sample and focused on low polynomial specifications, we still obtained large standard errors, which increased with decreasing bandwidth. As most effects resulting from retirement are probably small, a larger sample size would be needed to detect them and would allow using higher polynomial specifications and age–retirement interactions without overfitting concerns. Second, a related limitation is that several results were not robust to p-value corrections for multiple testing. While this might indicate the presence of type I errors, it is also possible that our study lacks the necessary power to detect such specific effects with sufficient certainty. In either case, there is greater uncertainty around these specific results, and they should be considered in future analyses involving larger sample sizes. Third, because of lack of data or inconsistent questioning across surveys, we did not include other mechanisms, such as doctor visits or dietary habits, which may have contributed to explain the results in the health domains. Fourth, our strategy to take panel attrition into account might not be enough to fully eliminate those concerns, as the panel we selected might present further problems of selection bias and lack of representativeness.

Finally, although the two baseline surveys were drawn to be representative for the Augsburg region, and the panel attrition of about 30 % is relatively low, if and how the findings are generalizable for the whole German population remains uncertain. On the one hand, differences between participants and non-participants were found to be small (Hoffmann et al., 2004). About 600,000 people live in the study area, which consists of both urban and rural parts including 80 small towns and villages. On the other hand, regional differences with respect to health behavior and health status have been reported for Germany (e.g. diabetes prevalence) (Schipf et al., 2014), showing that KORA participants are somewhat healthier than individuals from other German cohort studies. This indicates that our analyses might have overestimated positive effects from retirement, as participants in other samples are less likely to adopt a healthier lifestyle. Furthermore, we also might have underestimated negative effects, given the concerns that the population might be healthier than the general German population.

6. Conclusions

The present study provides novel evidence regarding the effect of retirement on biomedical risk factors for chronic cardiovascular and metabolic diseases. It also contributes to a growing body of research on the effect of retirement on health behavior and subjective health, using an analysis design that allowed causal inference. Retirement mostly represents a smooth transition for regular retirees, generally connected with improvements in subjective health but also with an increase in CHO/HDL levels, especially visible in regular retired males. Early retirement relates to worsening BMI, despite an increase in physical activity, which might have a long-lasting effect on the incidence of chronic disease, health care costs and longevity. Early female and low educated retirees (age 60) are mostly concerned by these negative effects. They should thus be regarded as high-risk groups and should represent potential targets for behavioral interventions. These should incentivize a more effective and health-conscious use of the additionally available time and changes in the daily routines in the retirement adaptation phase, targeting not only an adequate increase in leisure-time physical activity but also the other behavioral risk factors considered, which showed room for improvement.

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Data and code to replicate the results

All the data used in this submission can be requested from the KORA platform via project agreement (https://www.helmholtz-muenchen.de/kora/fuer-wissenschaftler/zusammenarbeit-mit-kora/index.html). The code used to analyze the data is available upon request from the corresponding author.

CRediT authorship contribution statement

Sara Pedron: Conceptualization, Project administration, Methodology, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Werner Maier:** Conceptualization, Investigation, Data curation, Writing - review & editing. **Annette Peters:** Conceptualization, Methodology, Resources. **Birgit Linkohr:** Data curation, Resources, Writing - review & editing. **Christine Meisinger:** Methodology, Investigation, Writing - review & editing. **Wolfgang Rathmann:** Methodology, Investigation, Resources, Writing - review & editing. **Peter Eibich:** Methodology, Formal analysis, Supervision, Writing - original draft, Writing - review & editing. **Lars Schwettmann:** Conceptualization, Supervision, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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Appendices A–M. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ehb.2020.100893.

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