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Aging and Health Care Expenditures:
A Non-Parametric Approach

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Abstract

One of the most important controversies in health economics concerns the question whether the imminent aging of the population in most OECD countries will place an additional burden on the tax payers who finance public health care systems. Proponents of the "red-herring hypothesis" argue that this is not the case because most of the correlation of age and health care expenditures (HCE) is due to the fact that the mortality rate rises with age and HCE rise steeply in the last years before death. The evidence regarding this hypothesis is, however, mixed. Our contribution to this debate is mainly methodological: We argue that the relationship of age, time to death (TTD) and HCE should be estimated non-parametrically. Using a large panel data set from the German Statutory Health Insurance, we first show that the parametric approach overestimates the expenditures of the high age classes and thus overstates the increase of future HCE due to aging. Secondly, we show that the non-parametric approach is particularly useful to answer the question whether age still has an impact on HCE once TTD is taken into account and find that it is clearly the case. This relationship is even more pronounced for long-term care expenditures (LTCE). We then show that the age-expenditure relationship is not stable over time: for many age classes, HCE in the last year of life grow considerably faster than HCE of survivors. We explore the impact of these findings on the simulation of future HCE and find that population aging will in fact contribute to rising HCE in the coming decades. We also find that the impact of different population projections provided by the statistical offices has a greater impact on these simulations than previously acknowledged. However, the total impact of demographics on future HCE and LTCE is dwarfed by the exogenous time trend, which is due to medical progress and increasing generosity of public LTC insurance.

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1 Introduction

One of the most important controversies in health economics concerns the question whether the imminent aging of the population in most OECD countries will place an additional burden on the tax payers who finance public health care systems. This matter is of great political relevance because in view of these developments, policy makers will soon have to make tough and highly unpopular decisions on measures for curtailing the expenditure growth, such as explicit rationing of health services.

Ever since the path-breaking article by Zweifel et al. (1999), many economists and politicians are convinced that the cross-sectional correlation between old age and high health care expenditures is a "red herring" because most of this correlation is due to the fact that the mortality rate rises with age and health care expenditures (HCE) rise steeply in the last years before death. From this they conclude that population aging as such does not pose a threat to the financial sustainability of public health care systems.

In the 20 years since, a host of subsequent papers have tested the "red-herring hypothesis", which states that when controlling for time to death (TTD), age per se has no or only a negligible effect on HCE.[1] These studies used data from various countries and employed various econometric approaches. For recent surveys see, e.g., Norton (2016) and Karlsson et al. (2018). A sizable share of the papers confirms the red-herring hypothesis (e.g. Zweifel et al. (2004), Dormont et al. (2006), Werblow et al. (2007), Shang and Goldman (2008), Felder et al. (2010), Wong et al. (2011), Hyun et al. (2015), and Howdon and Rice (2018)), but in some cases the empirical strategy appears doubtful: Hyun et al. (2015) use the number of chronic diseases as a regressor besides age and find that age is insignificant, but the former variable is certainly positively correlated with age, and the sample used by Howdon and Rice (2018) is highly selective since it comprises only data from persons in their last five to eight years of life so that the authors try to make inferences from the subset of decedents on the entire age-HCE relationship.

Other papers do find a significant and sometimes strong age gradient of HCE, e.g., Atella and Conti (2014), Gregersen (2014), Breyer et al. (2015), and Karlsson et al. (2018)). While all of these studies analyzed HCE in the usual definition, another branch of the literature dealt with long-term care expenditures (LTCE) and found that there is a significant positive age gradient with respect to these expenditures, even controlling for TTD (see, e.g., de Meijer et al. (2011), Balia and Brau (2014), and Karlsson and Klohn (2014)).

Thus not only are the findings on the relationship between aging and HCE contradictory and therefore inconclusive, but there are also methodological problems that have yet to be solved: most cited papers analyze cross-sectional data, but aging is a dynamic phenomenon, which is moreover accompanied by another important development over time, medical progress. Thus the combined impact of both determinants can only be properly measured by analyzing data that cover a time interval of at least one decade or more. Although the study by Breyer et al. (2015) uses a pseudo panel that covers 13 years, it suffers from the lack of individual data so that it could not be analyzed how HCE behave in the last years before a patient's death.

Our contribution to this debate is mainly methodological. First, we show that estimating the impact of age parametrically by using a polynomial of degree two or three (as is done in almost all studies) can be misleading.[2] In our data, such a parametric approach yields predicted expenditures which are too high for the highest age classes. Because it is mainly in these age classes that the number of insured will increase due to the demographic transition, simulations of future health care expenditures based on these expenditure estimates overstate the growth of per-capita HCE. We therefore propose to estimate the age-expenditure profile non-parametrically.

Secondly, a non-parametric estimation is better suited to determine whether age still has an impact on HCE once TTD is taken into account. In particular, if HCE of, say, survivors rises with age for some age classes but not for others this is immediately apparent from the non-parametric regression, while it is usually never determined and presented in the parametric approach. In our data, age has a significant impact on HCE both for survivors and decedents for a wide range of age classes.

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[1]This is only one of the four versions of the red-herring hypothesis that can be found in the literature. On the logical relations between these versions see Breyer and Lorenz (2019).

[2]An exception is the study by Karlsson et al. (2018) who measure age by a set of dummies representing 5-year age brackets.

Thirdly, making inference from the estimated age-expenditure profiles on future HCE is only valid if the age-expenditure profiles are stable over time. Extending the non-parametric approach to the time dimension shows that in our data, this is not the case. While the age-expenditure profile of persons in their last year of life is clearly decreasing with age, it is increasing with a higher than average growth rate. With stable age-expenditure profiles, per-capita HCE would decrease if in the future people died at a higher age. With the age-expenditure profile of people in their last year growing considerably faster than all other age-expenditure profiles, this will no longer be the case.

Fourthly, we recommend reporting confidence intervals not only for the estimated age-expenditure profiles, but also for the simulation of future HCE. This helps to better understand whether differences in growth rates determined in different studies are attributable to differences in the health care systems or just the result of the difficulty to estimate the age-expenditure profiles precisely: if the confidence interval of the simulated growth rate is wide, different growth rates in different studies may just be the result of different samples. If, however, it is very narrow, we can be more confident, that it is so for some underlying reason, like a difference in the health care system or a different kind of demographic transition. In our data, although some of the age-expenditure profiles cannot be estimated precisely in some age classes, the simulated growth rate has a remarkably narrow confidence interval.

Finally, we show that the impact of the population projections provided by the statistical offices can be much larger than usually acknowledged. In most studies, results for some median scenario are presented without discussing the results for alternative scenarios. In our data, using the revised projections of the 14th Population Projection of the German Statistical Office published in 2019 instead of the prior projection in 2013 for the simulation until 2050 has an effect similar in magnitude to the difference between the naive projection and the one with time to death taken into account.

For our study, we use a unique data set that spans 15 years and covers more than 300.000 individuals every year. The first two years of this data set were already used in Gandjour et al. (2008) to determine (in a descriptive way) the age-expenditure profiles for decedents (persons in their last 12 months of life) and survivors (all others) separately and to use these averages for projections of the purely demographic effect on future health care expenditures in the aging German society. In contrast, the present paper employs non-parametric methods to estimate age-expenditure profiles (as well as age-specific growth rates) for the following types of expenditures: those for medical care (HCE), for long-term care (LTCE), and total expenditures (TE), the sum of expenditures for medical care and long-term care. On the basis of these results and estimates of the time trend in expenditures we simulate the development of these expenditure types over the next three decades.

The remainder of the paper is organized as follows. In Section 2 we describe the data and in Section 3 we explain the methodology of estimating the determinants of HCE. In Section 4 we present the estimation results and in Section 5 we determine the impact of these results on the simulation of future HCE. Section 6 is devoted to a discussion of some of our findings, and Section 7 concludes.

2 Data

The data used in this study is from the Statutory Health Insurance Sample AOK Hesse/KV Hesse, which was collected and provided by the PMV Research Group.[3] It is a random sample of 18.75% of all persons who were insured with this sickness fund on January 1, 1998, or entered this sickness fund after that date. Once drawn into the sample, the person remains in the data set as long as he or she is insured with the sickness fund; if there is a break in the membership (e.g. due to staying abroad), the person is included in the sample after the break. In total, there are around 320,000 persons in the sample every year. The sample comprises the time period 2001 to 2015. 29,968 men and 34,447 women died in this 15-year observation period.

For every person the following information is given: gender, year of birth, all utilization of health care services covered by the statutory health insurance with the exact date, and expenditures, except for dental care, and the exact date of death, if the person has died. Descriptive statistics of the data set and a comparison with the entire German statutory health insurance (SHI) are given in Table 1.

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[3]A description (in German) can be found in Ihle et al. (2005).

Table 1: Descriptive statistics for 2015

	Sample	German SHI
Per cent female	0.4994	0.5207
Average age	44.0	44.1
Per cent over 65	0.2209	0.2203
Total per-capita expenditures	2,667 Euro	2,697 Euro
Mortality rate	0.01265	0.01143
Earnings per member	23,416 Euro	23,399 Euro

Sources: Bundesministerium für Gesundheit (2017), Drösler et al. (2017)

The daily expenditure data is aggregated into observations comprising a year: For survivors the aggregation is for the calendar year (e.g., 2001, 2002, and so on) irrespective of how many days the person was insured in that year. The expenditure data are annualized by first dividing the sum of expenditures in a year by the number of days the person was insured in that year, and then multiplying these daily expenditures by 365.25. In the estimation, these annualized expenditures are weighted by the number of days the individual was insured in that year.

For decedents, the aggregation is for the last year of life (day 365 to 1 before death), the penultimate year (day 730 to 366), the third from last (day 1095 to 731) and fourth from last year (day 1460 to 1096). Again, these expenditures are annualized by dividing by the number of days the individual was insured in the particular year before death, and multiplying by 365.25. Therefore, each year (whether leap year or not, or year before death or not) has the same "duration" of 365.25 days.

Some of the daily data refer to a period of time, most importantly expenditures for hospital stays and long term care. These expenditures are distributed evenly among the days of the time period. Expenditures of a hospital stay of a survivor including, e.g., the turn of the year 2005/06 are thus partly attributed to 2005 and partly to 2006. The same applies to decedents if, e.g., a hospital stay begins in the second to last year and ends in the last year of life.

If a decedent is observed for more than four years, the last four years of the daily observations are used to determine the yearly expenditures of a decedent; the remaining daily observations are aggregated into yearly expenditures of a survivor. When we determine the bootstrap confidence intervals for our estimations, such a decedent, if drawn into the bootstrap-sample for the last year before death, is always also drawn into the bootstrap-sample for the other years before death and the bootstrap-sample for the survivors.

For some of the analyses, a shorter time period than 2001 to 2015 has to be used: On the one hand, as the subset of survivors is defined as persons who lived at least 4 more years, the observation period for this subsample has to end in 2011. On the other hand, expenditure data for the last 12 months of life are not available for persons who died in 2001; therefore when estimating the expenditure for the last year of life, only persons who died in 2002 or later (with their expenditure data in 2001 or later) are considered. For the same reason, only persons who died in 2003 (2004, 2005) or later are considered when estimating the expenditure for the penultimate (third from, fourth from) last year of life.

As the age groups 95 years and above have very few observations (in particular if we distinguish between decedents and survivors), these age groups are aggregated into one group, 95^+. This fits with the population projections provided by the Statistical Office where mortality rates are given until the age of 99, so we can determine the number of individuals in the fourth from last year until the age of 95. We therefore present all results for age-expenditure profiles with age equal to zero up to 95^+.[4]

Besides this data set with individual level data, we use two more data sources: The data we use to determine the general time trend is the aggregated data published by the Federal Insurance Office (see Section 3.1 and Section 4.1). Finally, the population projections are from the Federal Statistical Office.

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[4]The only exception is when we do not distinguish between decedents and survivors and do not use the age-expenditure profile for the simulation, see Section 4.3.1.

3 Methods

In order to determine the increase of per-capita HCE (and similarly, LTCE) due to aging we have to estimate (a) the age-expenditure profiles and (b) the age-specific time trends. While (a) requires estimations in levels, (b) requires estimations in logs. In addition, the different levels of expenditure in the different years of our 15-year observation period (due to inflation, medical progress and a major health care reform in 2004, which led to significantly lower expenditures in that year) have to be accounted for. We therefore proceed in the following five steps.

3.1 Step 1: Isolating the overall time trend of per-capita expenditures

In the first step, we have to make the expenditures in the 15 years comparable by either deflating them to the initial year 2001 or inflating them to the final year 2015, of which we chose the latter because 2015 will also be used as the base year for the simulations of future expenditures.

For the inflation rate we do not use the change of the consumer price index because this would ignore expenditure trends that are specific to the health care system (as, e.g., the health care reform of 2004). Instead, we chose a procedure which isolates that part of the expenditure growth that is not due to changes in the age composition of the population. This can be done by determining the growth rate of per-capita expenditures where the latter are calculated holding the age-profile constant. The data we use for this procedure for the case of medical expenditures (both for per-capita HCE and the number of individuals in each age-gender-group) is from the entire German SHI (published by the Federal Insurance Office). For LTCE, the same procedure was performed using the age-specific per-capita expenditures from our data set.[5]

The procedure is as follows: Let

- $\bar{c}_{agt}$ denote the average HCE of persons of age a and gender g in year t,

- n_{agt} denote the number of persons of age a and gender g in year t and

- $\bar{n}_{ag(t,t+1)} = (n_{agt} + n_{ag(t+1)})/2$ denote the average number of persons of age a and gender g in two adjacent years t and $t + 1$.

Then we can determine per-capita HCE for year t, $\bar{c}^t$, and $(t + 1)$, $\bar{c}^{(t+1)}$, using the same average age structure $\bar{n}_{ag(t,t+1)}$ in both years as

$$\bar{c}^t_{(t,t+1)} = \frac{\sum_g \sum_a \bar{c}_{agt} \bar{n}_{ag(t,t+1)}}{\sum_g \sum_a \bar{n}_{ag(t,t+1)}} \tag{1}$$

$$\bar{c}^{t+1}_{(t,t+1)} = \frac{\sum_g \sum_a \bar{c}_{ag(t+1)} \bar{n}_{ag(t,t+1)}}{\sum_g \sum_a \bar{n}_{ag(t,t+1)}}. \tag{2}$$

The inflation factor (one plus the inflation rate) from year t to $(t + 1)$ is then given by

$$\pi_{t,t+1} = \frac{\bar{c}^{t+1}_{(t,t+1)}}{\bar{c}^t_{(t,t+1)}}. \tag{3}$$

Calculating the inflation factor in this way is analogous to the method of the Fisher price index (with age-gender-specific expenditures as prices and the number of persons in each age class as the basket of goods).[6] This index has the desirable feature that the total index can be decomposed into the index for subgroups of the population (e.g. men and women).

The expenditures of 2014 are made comparable to those of 2015 by multiplying them with the inflation factor $\pi_{2014,2015}$, those of 2013 by multiplying with the product $\pi_{2013,2014} \cdot \pi_{2014,2015}$, and so on.[7] The values of the inflation factors for both types of expenditures can be found in Table 2 in Section 4.1.

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[5]The Federal Insurance does not provide age-specific LTCE data.

[6]See Fisher (1922).

[7]Because the yearly expenditures of the decedents almost always consist of daily expenditures of two consecutive years, these inflation factors are applied to the daily expenditures before these are aggregated into the yearly observations.

Using these inflation factors has the great advantage that the average time trend is equal to zero. This makes the age-specific time trends we estimate in Step 3 easy to interpret: if the estimated time trend, say, for age class 20, is negative, this means, that expenditures for 20-year-olds have a smaller than average growth rate; if the estimated time trend is positive, expenditures increase faster than on average.

3.2 Step 2: Estimating age-expenditure profiles and their gradients

Because we are mainly interested in the estimate of the age-expenditure profile and their age gradient, we do not distinguish between the decision to utilize health care services at all and the amount of expenditures conditional on positive expenditures (see Jones (2011)); we therefore do not estimate a two-part model.

As it is well-known that the age-expenditure profiles differ in a non-trivial way between men and women, the two age-expenditure profiles are estimated separately. We therefore drop the index g in the following equations.

The non-parametric estimation procedure we employ is the local polynomial regression where the age-expenditure profile is determined by estimating the expenditure for each age in a separate regression.[8] The regression equation of this local regression can, in principle, be a polynomial (with respect to age) of any order: While the bias decreases when increasing the order, the variance only increases when going from an odd order to the next, even, order. It is thus advisable to use an odd order.[9] Because the age-expenditure profiles exhibit a high curvature in some areas, we use a polynomial of order three; this yields a better fit for those age classes where the slope of the age-expenditure profile changes quickly.[10]

Let c_{it} denote the expenditure and age_{it} the age of individual i in year t; then the estimated expenditure of the age-expenditure profile for a particular age, a_0, is the estimate $\hat{\beta}_0^{a_0}$ of the regression

$$c_{it} = \beta_0^{a_0} + \beta_1^{a_0}(age_{it} - a_0) + \beta_2^{a_0}(age_{it} - a_0)^2 + \beta_3^{a_0}(age_{it} - a_0)^3 + u_{it}^{a_0}, \tag{4}$$

where each observation is weighted according to the distance $age_{it} - a_0$, using the weighting function, i.e., the kernel, $K((age_{it} - a_0)/h)$.[11] In addition to the kernel, each observation c_{it} is also weighted by the number of days the person was insured during that year (see Section 2). This regression has to be run with a_0 set equal to zero, equal to one, and so on until the last age of the age-expenditure profile, i.e., $a_0 = 0, 1, 2, \ldots, a_{max}$. For each of these regressions, a different set of estimates $(\hat{\beta}_0^{a_0}, \hat{\beta}_1^{a_0}, \hat{\beta}_2^{a_0}, \hat{\beta}_3^{a_0})$ is determined, of which the series of $\hat{\beta}_0^{a_0}$ forms the age-expenditure profile.

Each of the two endpoints of the age-expenditure profile ($a_0 = 0$ and $a_0 = 95$) is estimated separately as a simple average (which could be considered a local polynomial regression with data on this age class only), and the expenditure data for these two age classes are ignored when estimating the profile for $1 \leq a_0 \leq 94$: Because expenditures for children in their first year ($a_0 = 0$) are very different from those in the second and following years, not treating this age group separately would increase the estimate for the second and following years unless the bandwidth is chosen to be very narrow;

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[8]See Fan and Gijbels (1996) and Härdle et al. (2004).

[9]See Fan and Gijbels (1996), p. 79.

[10]The results are very similar for a polynomial of degree one, for which the curves exhibit somewhat higher smoothness.

[11]For all estimations, we use the normal kernel and determine the optimal bandwidth by cross-validation. However, because of computing time, it is not feasible to determine the optimal bandwidth for each bootstrap sample. For the first 20 bootstrap samples, the mean-squared-error criterion is very flat in each of the samples within a considerable interval (which is larger for decedents than for survivors), so the optimal bandwidth varies considerably for these 20 samples. However, because the mean-squared-error criterion is so flat, it is no surprise that the results are very similar for different bandwidths. E.g., for our simulation, where we determine an increase of per-capita expenditures of about 10 per cent until 2050, the difference in this figure is always less than 0.1 percentage points when we vary the bandwidth between $h = 1$ and $h = 10$. Of course, the age-expenditure profile becomes somewhat less smooth if the bandwidth is reduced. We take an intermediate value of the optimal bandwidths of the 20 bootstrap samples separately for survivors and decedents, and use these two values for all estimations (i.e., for the four steps, Step 2 to Step 5, outlined in this section). When we determine the optimal bandwidth locally for each age class separately, the difference in the optimal local bandwidths between the different bootstrap samples is even more pronounced, while the mean-squared-error criterion is improved only slightly; we therefore opt for a constant bandwidth for the sake of simplicity.

this, however, is not appropriate, in particular for decedents, where the number of observations is very small in the low age classes. With the upper endpoint, the problem is that the group 95^+ does not only consist of 95-year-olds, as would be necessary for the local polynomial regression, but of those 95 and older. Therefore, the three groups ($a_0 = 0$, $1 \leq a_0 \leq 94$, and $a_0 = 95^+$) are estimated separately with the local polynomial regression.

We now turn to the estimation of the slope of the age-expenditure profile: In Equation (4), $\hat{\beta}_0^{a_0}$ is the estimate we are interested in, but the regression equation contains an odd number of higher order terms of $(age_{it} - a_0)$ to account for the slope and curvature of the age-expenditure profile in the neighborhood of a_0. If we are interested in $\beta_1^{a_0}$, we have to add an odd number of higher order terms besides $\beta_1^{a_0}$.[12] Therefore, the estimate of the (local) gradient of the age-expenditure profile is $\hat{\beta}_1^{a_0}$ of the estimation equation

$$x_{it} = \beta_0^{a_0} + \beta_1^{a_0}(age_{it} - a_0) + \beta_2^{a_0}(age_{it} - a_0)^2 + \beta_3^{a_0}(age_{it} - a_0)^3 + \beta_4^{a_0}(age_{it} - a_0)^4 + u_{it}^{a_0}. \quad (5)$$

Again, this regression has to be run with $a_0 = 0, 1, 2, \ldots, a_{max}$.

To save on computing time (which is especially relevant for the many bootstrap replications we perform), instead of using the individual observations c_{it}, we can use for each year t and age a the (weighted) average of the expenditures of all persons of that age in that year, given by

$$\bar{c}_{at} = \frac{\sum_i x_{it} d_{it} \mathbf{1}(age_{it} = a)}{\sum_i d_{it} \mathbf{1}(age_{it} = a)}, \quad (6)$$

where d_{it} is the number of days person i was insured in year t and $\mathbf{1}(age_{it} = a)$ is the indicator function equal to one if the age of person i in year t equals a. In the regression, these age-year-specific average expenditures are then weighted by the denominator of (6), i.e., the sum of the number of days of all persons of age a in year t.

The age-expenditure profiles (as well as the age-specific growth rates and the simulated expenditures in the next three decades) are estimated separately for medical care expenditures (HCE), long-term care expenditures (LTCE), and total expenditures (TE). In addition, when we distinguish between decedents and survivors, we estimate the age-expenditure profile separately for persons in their last year, penultimate year, third and fourth from last year, and for survivors.

3.3   Step 3: Estimating age-specific growth rates

To estimate the age-specific growth rates over time we have to apply the local polynomial regressions outlined in the previous paragraph to the log of the expenditure. Because we are interested in the (age-specific) growth of the expenditure of the age-expenditure profile, the dependent variable in the regression is not the log of the individual expenditure c_{it}, but the log of the age-year-specific average expenditure $\bar{c}_{at}$ defined above. Therefore, the regression equation is

$$\begin{aligned} \log(\bar{c}_{at}) \;=\; & \beta_0^{a_0} + \beta_1^{a_0}(age_{at} - a_0) + \beta_2^{a_0}(age_{at} - a_0)^2 + \beta_3^{a_0}(age_{at} - a_0)^3 \quad (7) \\ & + \beta_4^{a_0} t + \beta_5^{a_0} t(age_{at} - a_0) + \beta_6^{a_0} t(age_{at} - a_0)^2 + \beta_7^{a_0} t(age_{at} - a_0)^3 + u_{it}^{a_0}. \end{aligned}$$

Here, the age-specific growth rate for age a_0 is the estimate $\hat{\beta}_4^{a_0}$.[13] To determine the whole profile of the age-specific growth rates, this regression again has to be run for $a_0 = 0, 1, 2, \ldots, a_{max}$.

3.4   Step 4: Simulating future per-capita expenditures

To assess the size of the purely demographic impact on per-capita HCE and LTCE in the next three decades, we apply the estimated age-expenditure profiles from equation (4) to the age distribution and the age-specific mortality rates of future years as provided by the German Statistical Office in its 14th population projection, taking 2015 (the last year of our observation period) as the base year.

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[12]See Härdle et al. (2004), p. 98.

[13]Note that we have not incorporated a time trend in equation (4) in Step 2. This is because all expenditures are already inflated to the level of the expenditures in 2015. Therefore, adding a time trend has basically no influence on the estimate $\hat{\beta}_0^{a_0}$.

We distinguish between

(a) the naive projection based on the regression using all observations without distinguishing according to years before death and

(b) the projection with TTD taken into account by using separate regressions for survivors and decedents in their last, penultimate, third from last and fourth from last year.

Finally we add the general time trend determined in Step 1 to assess the impact of medical progress and other developments over time on the growth of HCE and LTCE.

3.5 Step 5: Bootstrap confidence intervals

For all estimations, i.e., the age-expenditure profiles and their gradients, the age-specific time trends, the simulated per-capita expenditures and the difference between the naive projection and the projection with TTD taken into account, we determine confidence intervals using the bootstrap method where individuals (not yearly observations of individuals) are drawn into the bootstrap sample. Because of the high skewness of the expenditures we determine the confidence intervals based on bootstrap percentiles[14] with a high number of 4999 repetitions[15].

4 Estimation results

In this section, we present the estimation results. Before that, we determine the overall time trend of per-capita HCE and LTCE in Section 4.1. We then present the different age-expenditure profiles: We begin with the comparison of the parametric and the non-parametric regression in Section 4.2; we next show the age-expenditure profiles without the distinction between decedents and survivors (Section 4.3.1), and then for survivors (Section 4.3.2) and decedents (Section 4.3.3); using the age-expenditure profiles of decedents and survivors, we can determine the share of the expenditures for those in their last year of life of total expenditures (Section 4.3.4). The gradients of the age-expenditure profiles are presented in Section 4.4, and the development of the age-expenditure profiles over time in Section 4.5.

4.1 Isolating the overall time trend of per-capita HCE

In Step 1, we determine the overall time trend of per-capita HCE and LTCE holding the age structure constant. The age-adjusted expenditure growth factors (one plus the growth rates) can be found in Table 2, which also contains the resulting inflation factors. From 2014 to 2015, per-capita HCE grew by 3.31 per cent; applying the inflation factor of 1.0331 to the expenditures of 2014 raises these expenditures to the same level as those for 2015. The inflation factor of 2013 is then the product of the growth rates of 2014 and 2013, and so forth.

It is easy to see that in the year 2004, average HCE were more than 4 per cent lower than in the previous year. The reason is that in January 2004 a major health care reform became effective, in which copayments were increased, some services were removed from the benefit package of the SHI and in the hospital sector a per-case payment system was gradually introduced. As can be seen from the inflation factors, this health care reform effectively brought per-capita HCE back to the level in 2001 (both years have almost the same inflation factor).

In the 14 years between 2001 and 2015, age-adjusted per-capita HCE and LTCE grew by 44.53 and 54.18 per cent, respectively (see the inflation factors of 2001), whereas the consumer price index only grew by 13.715 per cent in the same period. The ratio of the two figures for HCE, 1.4453/1.13715 = 1.271, shows that the growth in real terms was 27.1 per cent, or 1.73 per cent per year. The corresponding figures for LTCE are 35.6 per cent in the 14 years (1.5418/1.13715 = 1.356), or 2.20 per

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[14] See Efron and Tibshirani (1998), chapter 13.
[15] See Davidson and McKinnon (2004), chapter 5.3.

Table 2: Growth rates and inflation factors

	growth to following year		inflation factor	
year	HCE	LTCE	HCE	LTCE
2001	1.0270	1.0219	1.4453	1.5418
2002	1.0167	1.0121	1.4073	1.5088
2003	0.9584	1.0083	1.3842	1.4908
2004	1.0256	1.0178	1.4443	1.4785
2005	1.0241	1.0089	1.4082	1.4526
2006	1.0411	1.0104	1.3750	1.4398
2007	1.0410	1.0424	1.3207	1.4250
2008	1.0624	1.0613	1.2687	1.3670
2009	1.0260	1.0541	1.1942	1.2881
2010	1.0123	1.0176	1.1639	1.2220
2011	1.0136	1.0421	1.1498	1.2008
2012	1.0490	1.0756	1.1344	1.1523
2013	1.0468	0.9990	1.0814	1.0713
2014	1.0331	1.0724	1.0331	1.0724

cent per year. Comparing these rates to the average annual growth rate of real per-capita GDP, 1.27 per cent, shows that age-adjusted real HCE, and even more so, LTCE grew considerably faster than real GDP, both in per-capita terms.

4.2 Comparison of non-parametric and parametric regression

In this and the following sections, where we present the estimated age-expenditure profiles, we always also show 95% confidence intervals based on bootstrap percentiles. We begin with the comparison of the parametric and the non-parametric method.

(a) Age-expenditure profiles

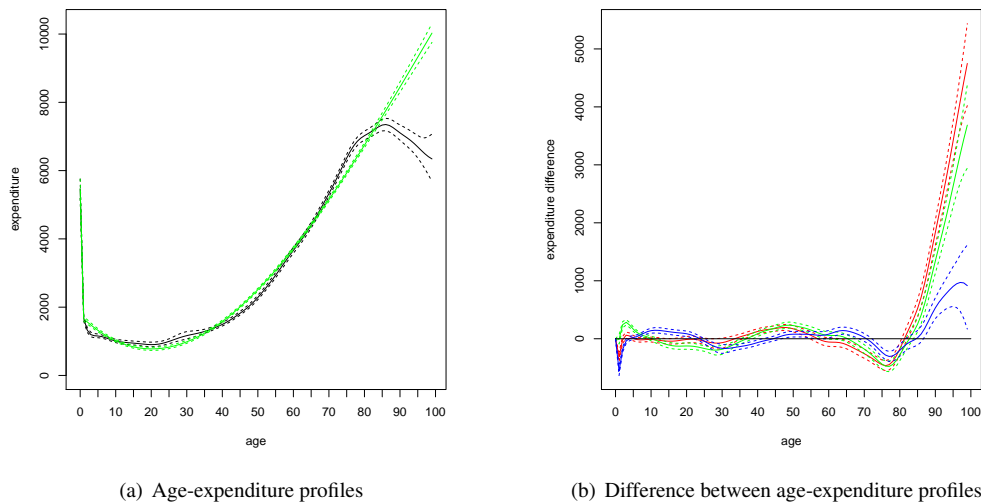(b) Difference between age-expenditure profiles

Figure 1: Comparison of parametric (polynomial of degree two (red), three (green) and four (blue)) and non-parametric regression (black) for HCE of men

Figure 1 shows that the parametric approach can be severely misleading: Figure 1(a) compares the non-parametric estimate with a third-order polynomial, where the dependent variable measures HCE for men. The figure shows that the polynomial cannot capture the decline of HCE with age beyond

age 80. Figure 1(b) shows the difference between the parametric and the non-parametric regression (with the confidence interval of this difference), where a positive value means that the estimate of the parametric approach is too high. At the upper end of the age-expenditure profile, the difference is about 4,500 Euro for a polynomial of degree two, and 3,500 Euro for a polynomial of degree three.

The opposite holds for LTCE: For the upper end of the age-expenditure profile, estimated expenditures are 6,000 Euro too low for a polynomial of degree two, and still 3,000 Euro too low for a polynomial of degree three.

4.3 Age-expenditure profiles without and with TTD taken into account

4.3.1 Age-expenditure profiles without distinction between survivors and decedents

In the remaining part of this paper, all age-expenditure profiles shown are from the non-parametric regression. We begin with the naive approach without the distinction between survivors and decedents. The results are presented in the left column of Figure 2.

Figure 2(a) shows that per-capita HCE are high in the first year of life, decline sharply in the second year and remain low throughout youth and young adulthood. In higher age groups HCE of men are on average higher than those of women because in these age groups there are more decedents among men than among women (see also Figure 7 in the Appendix). Finally, HCE decline significantly from about age 85 for both genders.

In contrast to HCE, Figure 2(c) shows that per-capita LTCE are considerably higher for women than for men from about age 80 and even exceed HCE for women over 90. Looking at the sum of both types of expenditures, TE, in Figure 2(e) shows that between age 55 and about 85, the excess spending for men in the HCE category translates into higher TE than for women, while beyond age 85 the higher LTCE for women more than compensates for the higher HCE for men. Besides that, rapidly increasing LTCE with age more than compensate for the decline of HCE with age beyond age 85 so that TE continues to rise up to age 100, where data become too rare to allow any meaningful statements.
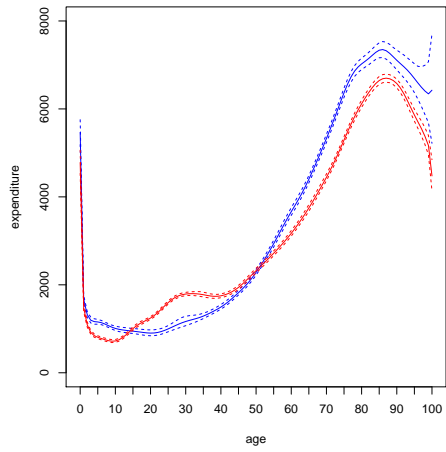
4.3.2 Age-expenditure profiles of survivors

We now turn to the separate estimation according to survival status. The right column of Figure 2 shows the age-expenditure profiles for male and female survivors, i.e. those individuals who are known to have lived at least 4 years beyond the health care utilization used to estimate these profiles.[16] Figure 2(b) shows the result for HCE: These expenditures are high (around 5,000 Euro) in the first year, then decline until about age 10 for females and 18 for males, where they reach their minimum at about 800 to 1,000 Euro. There is a hump for women between 20 and 45, which is certainly due to maternity costs, and from then on expenditures are remarkably similar for both genders and increase with age until they reach a maximum of about 4,600 Euro at age 78 for men and age 85 for women before they decline slightly (but for men not significantly) until age 95. The difference between men and women found in Figure 2(a) where all individuals are included is indeed due to the higher mortality rates of men.[17]

Figure 2(d) shows that the age-expenditure profiles for LTCE for survivors look similar to those for all individuals; however, the difference between LTCE for women and men at ages beyond 80 is now even bigger. The same result – a large gap between women's and men's expenditures for all age groups over 80 – remains true for the sum of HCE and LTCE, TE (Figure 2(f)). Besides that, there is a noticeable kink in the age profile of TE for men around age 80. This is the combined effect of a relatively moderate increase of LTCE with age between 80 and 90 and the sudden reversal of the age-HCE relationship around age 80.

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[16]Notice that these curves do not extend beyond age 96 because of the 4-year distance from death and the thinness of data beyond 100.
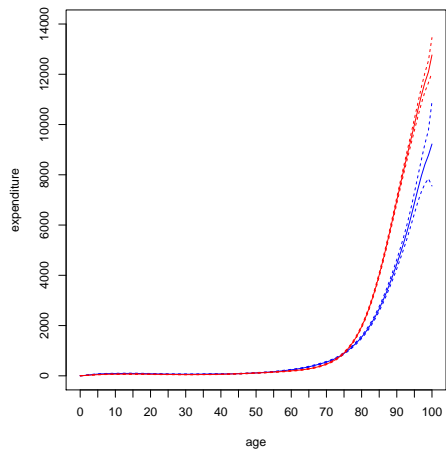
[17]Another possible explanation is that the mortality rates are equal, but men incur higher expenditure in their last years of life. We show that the opposite holds in Section 4.3.3.
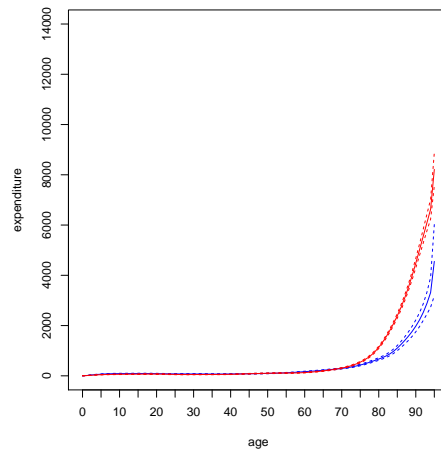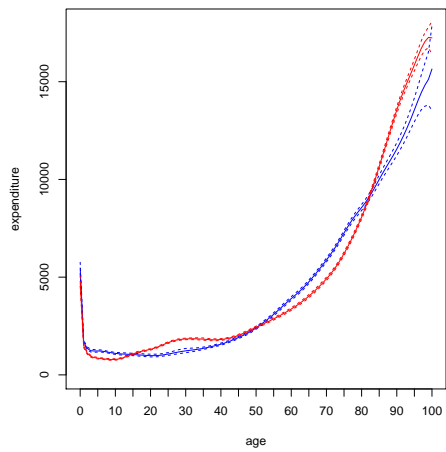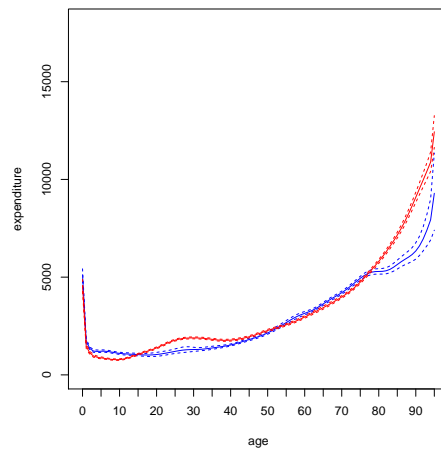
(a) HCE, all
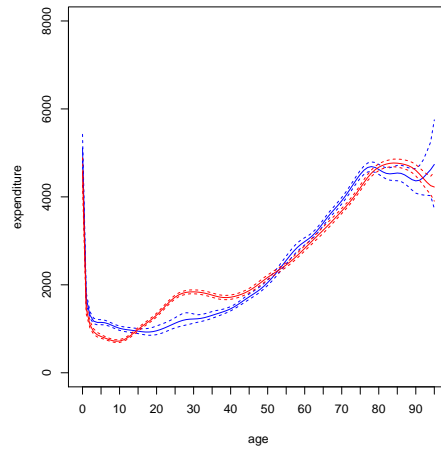
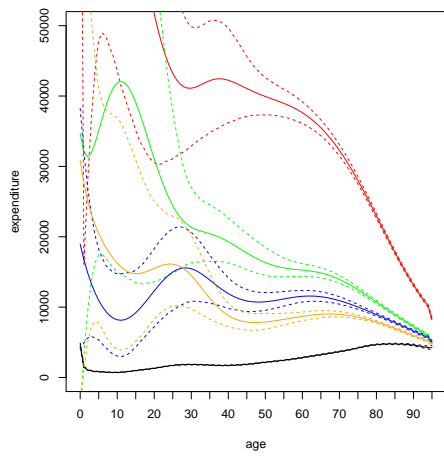(b) HCE, survivors
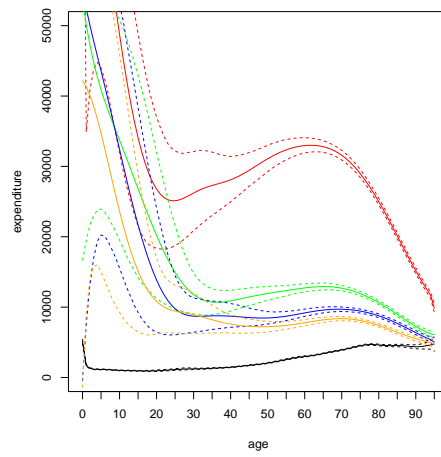
(c) LTCE, all

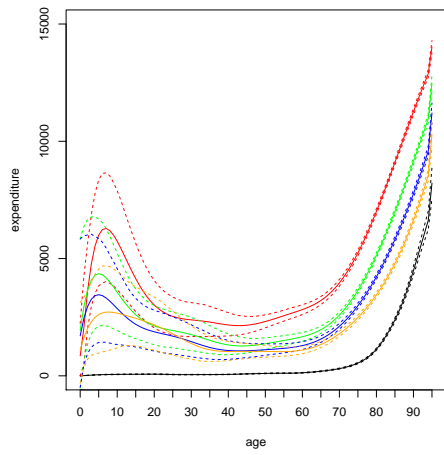(d) LTCE, survivors

(e) TE, all

(f) TE, survivors

Figure 2: Estimated age-expenditure profiles for men (blue) and women (red). Left column: without distinction between decedents and survivors. Right column: Survivors
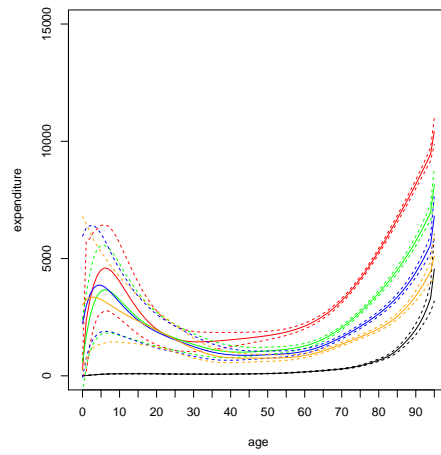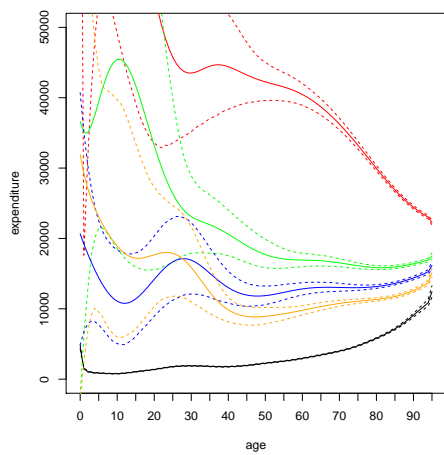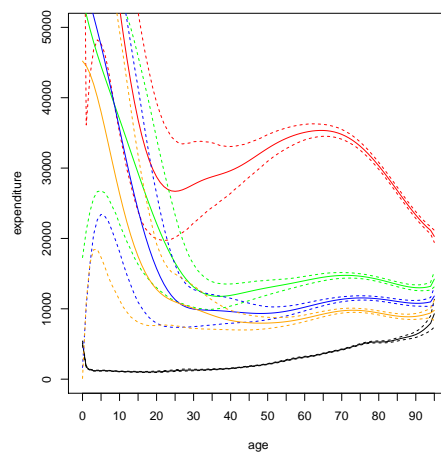
11

(a) HCE, women

(b) HCE, men

(c) LTCE, women

(d) LTCE, men

(e) TE, women

(f) TE, men

Figure 3: Estimated age-expenditure profiles of HCE for decedents: last year of life (red), penultimate year (green), third from last (blue) and fourth from last (yellow); and for survivors (black).

4.3.3 Age-expenditure profiles of decedents

For decedents, the age-expenditure profiles for HCE look completely different from the ones for survivors, which is evident from Figures 3(a) (for women) and 3(b) (for men). In these figures the red curve represents expenditures in the last year of life, the green curve those in the penultimate year and the blue and yellow curves those in the two preceding years, respectively, whereas the black curve is a reproduction of the corresponding profile for survivors (from Figure 2(b)). Before interpreting the shape of the curves, it should be taken into account that the number of decedents between ages 1 and 40 is extremely low (on this see Figure 7 in the Appendix); therefore, the confidence intervals are large, so the shape of the curve in these age classes should be interpreted with great caution.

The main results from these two figures are:

- In all age groups, HCE for decedents in each of the last 4 years of life exceed those for survivors by a large amount, which becomes small only for the oldest age groups. However, HCE in the very last year are still about twice as large as those for survivors even at age 95.

- In the last four years of life, expenditures for women are noticeably higher than those for men.

- The age gradient of medical spending in the last two years of life is negative for women beyond age 40 and for men beyond age 70 (on this see also the following section).

- Expenditures are the lower the farther away a person is from death and the difference between penultimate, third and fourth year before death is small compared to the gap between the last and the penultimate year.

In absolute terms, the average cost of the last year of life peak at around 32,000 Euro for men who die between 60 and 65, whereas for women who die between 40 and 45 years of age, they even exceed 40,000 Euro, and in both sexes they decline monotonously to less than 10,000 Euro when a person dies at an age over 90 years.

Turning to the age-expenditure profiles for LTCE in the last 4 years of life (Figures 3(c) and (d)), we see that these expenditures are very high for the few children who die around age 10, stay relatively low between age 20 and 70 and increase steeply beyond that age. For women who die at age 95, LTCE in the last year of life amount on average to almost 15,000 Euro (where this average includes persons who do not use any LTC services in their last year).

4.3.4 Share of expenditures in the last years of life

Using the age-expenditure profiles for men and women in their last, penultimate, third and fourth from last year and of survivors and multiplying with the respective number of individuals (in the German SHI in 2015), we can determine the share of expenditures (of all expenditures) incurred by those in their last, penultimate, third and fourth from last year. The result can be found in Table 3.

Table 3: Distribution of expenditures over the life cycle

	HCE		LTCE		TE	
	women	men	women	men	women	men
last year	8.3%	10.9%	17.9%	18.6%	9.8%	11.7%
penultimate	4.0%	4.6%	13.4%	12.3%	5.4%	5.3%
third last	3.4%	3.7%	10.8%	9.3%	4.5%	4.3%
fourth last	3.0%	3.3%	8.8%	7.1%	3.9%	3.6%
other	81.3%	77.5%	49.1%	52.6%	76.4%	75.1%

They show that 8.3 per cent of HCE for women and 10.9 per cent of the expenditures for men fall upon the last 12 months of life, whereas those in the last 4 years are about twice this size. Including expenditures for LTC increases the figures for the last year to 9.8 per cent for women and 11.7 per cent for men, and in the last 4 years to 23.6 per cent for women and 24.9 per cent for men.[18]

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[18]These numbers are comparable and, if anything, slightly higher than the results of two recent studies by Bakx et al. (2016) and Karlsson et al. (2016).

4.4 Gradient of the age-expenditure profile for HCE

The question whether age still has an effect once TTD is taken into account does not have the same answer for all age classes. Simply inspecting Figures 2(b) and 3(a) and (b), there appears to be a positive age gradient for survivors and a negative one for decedents, at least for certain age brackets; Figure 4(a) now shows that the positive age gradient for survivors is statistically significant for ages 40 to 80 for women and 35 to 75 for men. For decedents, the negative age gradient is statistically significant from age 57 for women and from age 65 for men, see Figure 4(b).
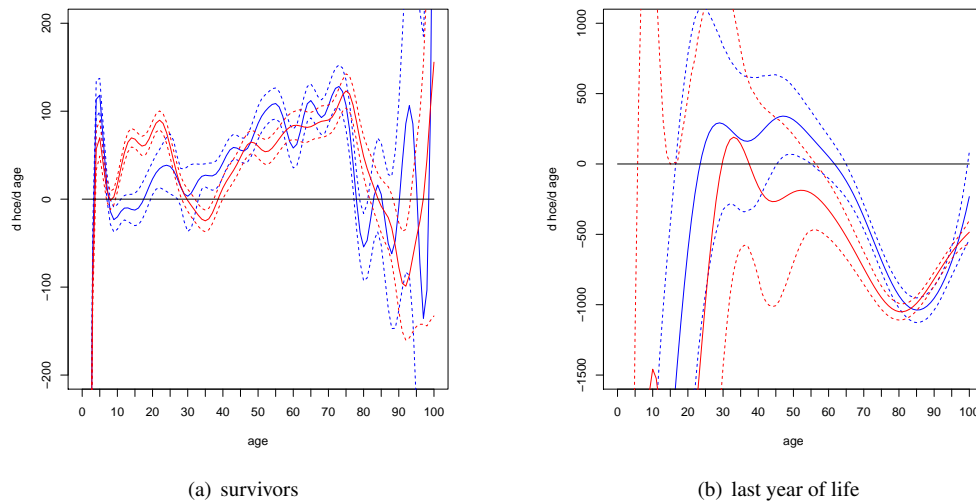

(a) survivors   (b) last year of life

Figure 4: Age-gradient for HCE; women (red) and men (blue)

4.5 Age-specific time trends

We now turn to the age-specific time trends. Notice that because we purged our data of the general time trend (see Section 4.1), all results in this section are age-specific deviations from the general time trend. If, e.g., the age-specific time trend of the higher age classes was positive (i.e., above the general time trend), this would amplify the impact of aging as those age classes that will become relatively more important, have expenditures which grow faster than on average.

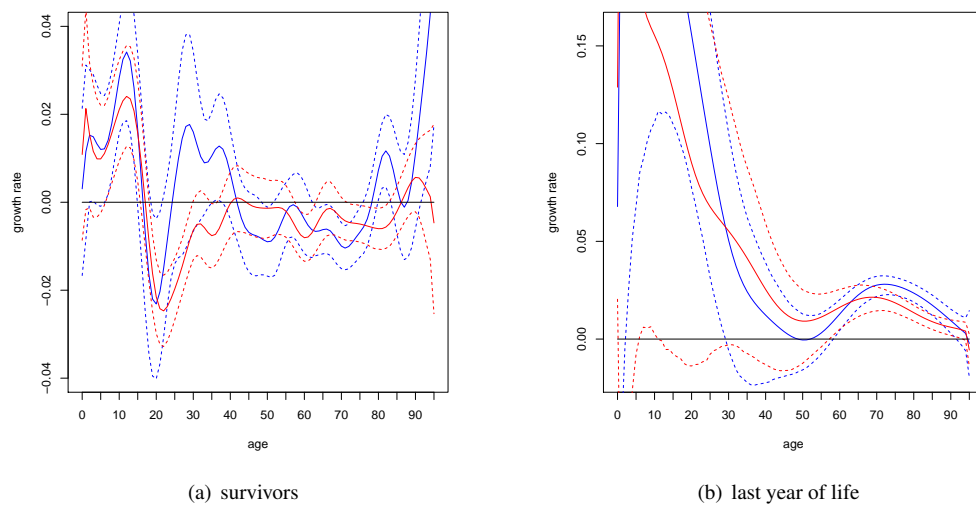(a) survivors   (b) last year of life

Figure 5: Age-specific time trends (growth rates) as deviations from general time trend, HCE; women (red) and men (blue)

Figure 5(a) presents the profile of age-specific time trends (annual growth rates) for HCE of survivors. The figure shows that significant (but small) deviations occur only in three age-sex groups:

- Boys and girls between 5 and 15 years exhibit faster growth, but as the level of HCE is relatively low at this age, the impact on total HCE should be small.

- Women in their 20s and early 30s have slower growth (presumably due to the shifting of maternity-related expenditures into higher age brackets), but again the overall impact should be small.

- Finally, men between 63 and 76 exhibit slightly slower expenditure growth, but the difference in the annual growth rates is only on the order of one-half of a percentage point.

Among decedents, we find the most significant age-specific expenditure trends for persons in their last year of life, which are presented in Figure 5(b), again referring to HCE. Apart from men below 30, for whom the number of deaths is extremely small, we notice a significant positive deviation for all age groups between 60 and 90, which is quite sizable: an up to 2 per cent extra growth rate per year for women and up to 3 per cent for men. One possible explanation hints at the advances in the treatment of various types of cancer in the final stage (see Breyer et al. 2020).

5   Simulation results

In this section, we present the simulation results for the forecast of future HCE. In Section 5.1 we compare the naive simulation with the one with TTD taken into account. Section 5.2 shows the impact of different population projections, Section 5.3 the impact of taking the age-specific time trends into account. The results including the overall time trend are given in Section 5.4.

5.1   Simulation results without and with TTD taken into account

Figure 6 and Table 4 show the results for the naive simulation vs. the simulation with TTD taken into account. Although parts of the age-expenditure profiles of decedents cannot be estimated precisely, the confidence intervals are remarkably narrow; nevertheless, they are somewhat larger for the simulation with TTD taken into account than without.
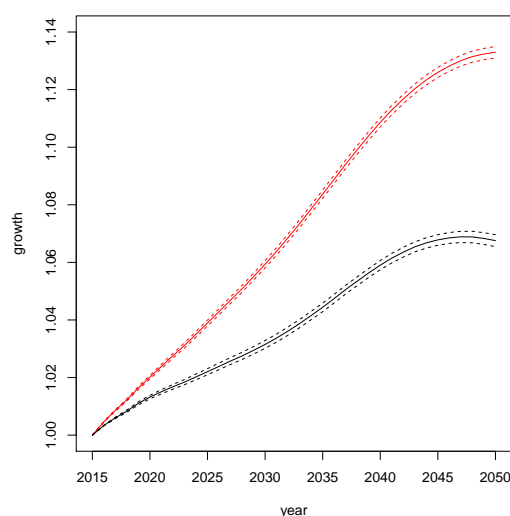

Figure 6: Simulation of future HCE, without (red) and with (black) TTD taken into account

Table 4: Simulated increase in HCE, demographic change only

year	HCE		LTCE		TE	
	distinction between survivors and decedents					
	without	*with*	*without*	*with*	*without*	*with*
2015	1.000	1.000	1.000	1.000	1.000	1.000
2020	1.020	1.013	1.077	1.065	1.028	1.020
2030	1.059	1.032	1.229	1.183	1.082	1.051
2040	1.109	1.059	1.414	1.315	1.149	1.091
2050	1.133	1.068	1.689	1.543	1.207	1.127

The results confirm the previous literature (see, e.g., Stearns and Norton 2004) in several ways. First, taking time-to-death into account in the regressions explaining HCE does reduce forecasts of the demographic effect on future per-capita HCE growth, if only slightly. Over a 35-year period from 2015 to 2050, HCE per capita are predicted to rise by 6.8 per cent for purely demographic reasons (instead of 13.3 per cent when no distinction between survivors and decedents is made).

Including LTCE, the respective growth amounts to 12.7 per cent (instead of 20.7 per cent), which translates into a constant annual growth rate of .34 per cent. LTCE alone increase considerably by 54 per cent over this 35-year period because of the changing age composition.

5.2 Impact of different population projections on simulation results

Using different versions of the population projection of the German Statistical Office based on faster or slower growth in life expectancy has only a very small effect on the overall growth of medical or total expenditures (and moderate effects on LTC expenditures), as is shown in Table 5. However, using the previous population projection published just six years ago shows a much higher effect. In fact, the difference between the two population projections published in 2013 and 2019 for LTCE is 25.2 percentage points (1.795 - 1.543), much higher than the difference between the naive projection and the projection with TTD taken into account (14.6 percentage points). For HCE, the corresponding figure is 3.4 percentage points, still more than half of the 6.5 percentage points for the difference between the naive projection and the projection with TTD taken into account.

Table 5: Simulated increase in expenditures until 2050, for different population projections

	HCE		LTCE		TE	
	distinction between survivors and decedents					
	without	*with*	*without*	*with*	*without*	*with*
base (BV14 G2 L2 W2)	1.133	1.068	1.689	1.543	1.207	1.127
slower growth in LE (BV14 G2 L1 W2)	1.117	1.072	1.577	1.488	1.178	1.124
faster growth in LE (BV14 G2 L3 W2)	1.149	1.064	1.803	1.598	1.235	1.132
BV13 (base)	1.177	1.102	1.881	1.795	1.271	1.178

Explanation of the abbreviations: BV13, BV14: 13th and 14th population projection; G2: total fertility rate constant at 1.55 children per woman; L1: life expectancy at birth rising by 2060 to 82.5 (86.4) years for boys (girls); L2: ditto with 84.4 and 88.1 years, respectively; L3: ditto with 86.2 and 89.6 years, respectively; W2: average annual net immigration of 221,000 persons

5.3 Simulations with age-specific time trends taken into account

If, in addition to the distinction between survivors and decendents, we also take the age-specific time trends into account (see Section 4.5), the growth of expenditures until 2050 becomes much larger, but the confidence intervals become huge (more than 100 percentage points). Thus, while it is important to keep in mind that the age-expenditure profiles are not stable over time, incorporating their development into the simulation does not yield results with a reasonable degree of precision, even for a data set as large as the one we use. This shows why it is important to determine the confidence intervals not only for the age-expenditure profiles, but also for the simulations.

5.4 Adding the overall time trend

In Table 6, we add the time trend to simulate total growth of expenditures on the basis of our estimated model. In doing so, we distinguish between medical and LTC inflation, which were calculated in Section 4.1 as 1.73 and 2.20 per cent annually, respectively. Applying these numbers leads to a total 35-year growth of HCE by 94.5 per cent. LTCE are even predicted to more than triple so that total per-capita expenditures TE are calculated to rise by 109.5 per cent, which translates into a constant annual growth rate of 2.1 per cent, which is more than six times as much as the demographic effect calculated from the results of Table 4. This suggests that medical progress raises health care expenditures more than 5 times as fast as does the demographic change that will occur in Germany.

Table 6: Simulated increase in HCE, with overall time trend

year	HCE		LTCE		TE	
	distinction between survivors and decedents					
year	*without*	*with*	*without*	*with*	*without*	*with*
2015	1.000	1.000	1.000	1.000	1.000	1.000
2020	1.111	1.104	1.201	1.187	1.121	1.113
2030	1.369	1.334	1.703	1.639	1.406	1.368
2040	1.702	1.625	2.435	2.265	1.783	1.696
2050	2.063	1.945	3.616	3.303	2.235	2.095

6 Discussion

The main message of this paper is a methodological one: when trying to assess the impact of age on public expenditures for health and long-term care, simple measures of age such as polynomials of degree 1 or 2 (or sometimes 3), which are commonly used in the literature, cannot capture the highly nonlinear empirical relationship between age and HCE adequately. We have tried to demonstrate that a nonparametric approach is better suited to analyze this relationship. However, even then a number of critical issues remain that pertain partly to methodology and partly to an interpretation of the results:

1. When distinguishing between survivors and decedents, a decision has to be made for how many years before death a person is regarded a decedent. Ideally, this dividing line should be drawn according to the criterion how long before its occurrence imminent death has an influence on HCE and thus should depend upon the cause of a person's death. For people dying from cancer, e.g., the time span between the onset of the disease and death varies greatly by the type of cancer and can amount to many years. In contrast, victims of fatal accidents never reach the status of a decedent for a time span worth mentioning. Thus the decision will typically be made for practical reasons: each additional year before death that is shifted into the decedent category implies the loss of one year of data in the survivor category. In existing studies with this distinction the time span before death is usually defined between 3 and 4 years, and we have adopted this convention.

2. An important question is how the observed expenditure data have to be interpreted: Do they constitute demand or even medical "need" or are they the result of rationing? Whenever it is the purpose of the studies to assess the future sustainability of health care financing systems, it seems desirable to forecast future need however this is defined. Moreover, need must be defined relative to available medical technology, and time series or panel data have the important advantage to take advances in technology into account. However, they are also affected by other time-varying factors such as income growth, which makes people willing to spend a larger part of GDP on health care, and, on the opposite side, political attempts to contain HCE (as was shown with respect to the German health care reform of 2004) so that it is no longer certain that a pure demand is measured. If the results of the simulations of future expenditures suggest that the health care system will become financially unsustainable, this shows that future attempts to contain expenditures will have to become even harsher than past ones.

Another point, which is related to the last one, concerns the nature of social LTC insurance in Germany, which covers only part of the costs of LTC. At its introduction in 1995, this share was meant to be 50 per cent. But as the insurance coverage for the different severity classes was fixed in absolute Euro amounts and these amounts were raised subsequently only in longer time intervals, the true share has declined somewhat over the last 25 years, and it is only these expenditures (and not total LTC costs) that we see in our LTCE data. Recently, there are strong voices in the political debate which demand that instead of fixing the insurance coverage, the copayments for nursing home care should be fixed in absolute amounts and adjusted only for general inflation. If this principle became law, future increases in public LTCE would be even stronger than estimated in our simulation exercise.

3. What have we learned from the analysis with respect to the famous red-herring hypothesis? Does population aging due to rising longevity have a positive impact on HCE? The answer to this decades-old question relies on a number of factors that we have tried to disentangle in this paper:

   - the age gradients of HCE for the two artificially created periods of human life: the last 4 years and all previous years,

   - the shares of expenditures of the respective groups,

   - the changes of the age-expenditure profiles over time, and

   - possible direct effects of rising longevity on HCE.

Although only about 20 per cent of HCE are incurred by people in their last 4 years of life, there is a strong negative age gradient, which by itself would dampen HCE when longevity rises and thus people die at higher ages. On the other hand, the other 80 per cent of HCE fall upon people who will survive at least 4 more years, and these expenditures have a strong positive age gradient above age 40. Furthermore, HCE in the last year of life for the vast majority of people who die at age 60 or above increased particularly strongly over time, and these two factors contribute to a positive effect of aging on HCE, which is even more pronounced for LTCE. As a result, the total effect is an annual increase of per-capita TE by one-third of a percentage point, which is not huge, but still positive.

7   Concluding remarks

In this paper, we have used non-parametric regression methods to estimate the age-expenditure profiles of health care expenditures separately for men and women and for persons in their last 4 years of life (decedents) and for all others (survivors) and to simulate the future development of HCE and LTCE for Germany with its aging population for the coming decades. We can summarize our main findings in the following statements.

In contrast to the "red-herring" claim, aging has a positive impact on per-capita expenditures, and this is small for medical care expenditures, but much larger for expenditures on long-term care. This growth is dwarfed by the exogenous increase in HCE over time, which we attribute to medical progress, and it will be subject to future research to find out what treatments for what conditions

are the main contributors to this development. Preliminary results from Breyer et al. (2020) suggest a special role of cancer treatments.

When applying the results of our estimations to a simulation of per-capita expenditures on health and long-term care in the German SHI system, we find an annual growth rate of more than 2 per cent, which exceeds even the most optimistic forecasts of per-capita GDP growth in Germany. The results therefore imply that in the long run, the financial sustainability of the German health care financing system is seriously jeopardized.
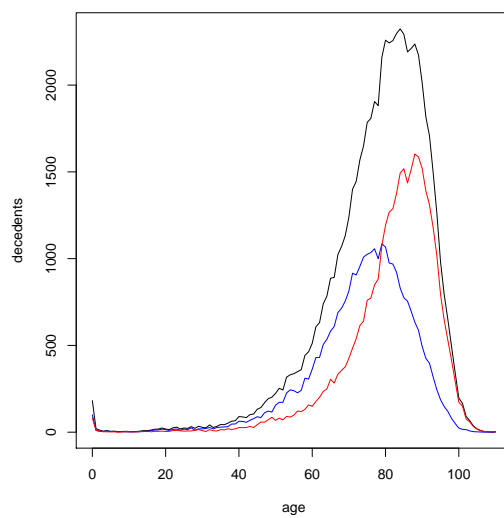
Appendix

Figure 7: Total number of decedents by age (2001-2015): women (red), men (blue), and total (black)

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