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Insight into the Female Longevity Puzzle: Using Register Data to Analyse Mortality and Cause of Death Behaviour Across Socio-economic Groups

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Abstract

This paper analyses the complexity of female longevity improvements. As socio-economic status influence health and mortality, we partition all individuals, at each age and year, into ten socio-economic groups based on an affluence measure. We identify the particular socio-economic groups that have been driving the standstill for Danish women and within each socio-economic group we further analyse the cause of death pattern. Further, we compare the forecast performance of the Lee-Carter model with the multi-population Li and Lee model. The decline in life expectancy for Danish women is present for all subgroups, however with particular large decreases for the low-middle and middle affluence groups. We find that causes of deaths related to smoking partly contribute to the slowdown in female longevity. However the lack of improvements in deaths relating to ischemic heart diseases is dominant in explaining the slowdown and the following catch up effect in life expectancies.
JEL classification: J11; C53; G22
Keywords: Mortality; Affluence Groups; Social Inequality; Cause of Death; Health; Multi-population Modelling

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1 Introduction

Over the last century significant increases in life expectancy has been observed for the developed countries. However, this observed decline in mortality rates is not a general pattern, as periods with gender-specific divergence between countries have emerged. In particular in the Scandinavian countries we have observed a decrease in the mortality rates for Norwegian and Swedish females, but a stable or in some cases even increasing mortality rate for Danish females in the period from 1980-1995. A similar divergence has not been observed for Scandinavian males. This is an interesting puzzle: Why do women in some developed countries experience increased longevity whereas women in other developed countries experience a stable or decreased longevity? This phenomena is not unique to the Scandinavian countries. Meslé and Vallin (2006) showed that the USA and the Netherlands exhibit a similar slowdown in life expectancy like the Danish case whereas other countries like France and Japan continue to display a stable positive growth in life expectancy. See also Rau et al. (2008) that identifies similar issues for the oldest-old. The study by Meslé and Vallin (2006) finds that gains in life expectancy for Japan and France were partly due to a greater reduction of cardiovascular mortality at old ages.

Previous research has investigated the observed low life expectancy for Danish women; especially the relation between low life expectancy and smoking behaviour of Danish women has been studied. The papers by Jacobsen et al. (2002) and Jacobsen et al. (2004) found that the lower mortality for Danish women is due to a higher mortality for women born between the first two world wars, and these cohort effects was not present in a similar extent for Sweden and Norway. Further, they indicate that the lower life expectancy for Danish women in this period could be due to smoking habits as Danish women in this cohort started smoking earlier compared to Norwegian and Swedish women. This was investigated further in Jacobsen et al. (2006) using cause of death data for Denmark finding a larger prevalence of smoking related causes of deaths for Danish women in this cohort. As an alternative to smoking frequencies (but likely correlated) drinking frequencies have also been considered as an explanation for the lower life expectancies for Danish women in Bjørk et al. (2008) and Koch et al. (2015).

Adherence to a lower socio-economic group is positively correlated with poorer health and thus higher mortality rates, see Saurel-Cubizolles et al. (2009), Van Doorslaer et al. (1997) and Borrell et al. (2003). Previous indicators of socio-economic position include level of education, occupational group, or income, see e.g. Elo and Preston (1996), Brønnum-Hansen and Juel (2004), Kunst et al. (1999), and Brønnum-Hansen and Baadsgaard (2012). Moreover several of these studies suggest that social inequality is increasing over time and greater for men compared to women, see Cristia (2009), Marmot and McDowall (1986), Koskinen and Martelin (1994), Cesaroni et al. (2006), Mackenbach et al. (2003), and Brønnum-Hansen and Baadsgaard (2012). In terms of Danish studies, Brønnum-Hansen and Juel (2004) investigate the impact of smoking on the social gradient in health expectancy for four educational groups using a National Health survey data from 2000 and Brønnum-Hansen and Baadsgaard (2012) investigate social inequality in terms of life expectancy for four subgroups using register data primarily based on level of education at age 30. They find an increasing inequality in terms of life expectancy. We deliberately avoid using educational attainment as an indicator for socio-economic adherence due to the increasing concentration amongst the least well of individuals in the lowest education group over time. For instance the lowest education in 1985 would contain a substantially larger share of the population compared with 2012 as low level of education used to be more common. This selectivity might introduce a downward bias in life expectancy as one is increasingly considering the worse off individuals whereas the more well of individuals would now be part of a higher education group.[1] Specifically for the Danish case we also avoid problems related to the education variable only being available for individuals born after 1922, i.e. younger than age 63 in 1985.

This paper analyses the complexity of female longevity improvements by identifying which socio-economic groups have been driving the standstill in life expectancy for Danish females. Moreover, we analyse which causes of deaths have been causing this development. A better understanding of the mechanisms underlying these inequalities will enable policymakers in defining the most effective preventive policies. By using a very unique and extensive multi-population register dataset provided by Statistic Denmark and Statistic Norway we construct an affluence measure based on the individual's financial status in terms of income and wealth, see Cairns et al. (2016). This enable us to obtain a very fine and clear partitioning between 10 subgroups both in terms of life expectancy and mortality rates in both Denmark and Norway for the time periods $1980-2012$ and $1980-2008$ respectively. A positive feature of comparing Denmark and Norway is that both countries are similar in their access to health care, social security and general living standards. Naturally, the financial status does not affect longevity directly, however adherence to a particular socio-economic subgroup is closely related to exposures affecting mortality patterns, such as smoking, visits to the doctor, living conditions, work environment, job type and labour force participation. The causality between income and health is well established, see e.g. Ettner (1996). Finally, this paper offers further insights on mortality modelling and forecasting for socio-economic groups. The importance of using single- or multi-population models is investigated using the well-known Lee and Carter (1992) (LC) and Li and Lee (2005) (LL) model which are investigated in terms of fit and forecasting ability across the 10 affluence groups. Further, we compare the benefit of having more homogeneous populations by disaggregating into subgroup.

We are able to identify differences in life expectancy of up to 7-8 years for 50 year old males and 5-6 years for 50 year old females in the mid-1980s. Hence, we confirm that the social inequality in mortality is greater for men than for women. We discover that the decline in life expectancy for Danish women is present for all subgroups, however with particular large decreases for the low-middle and middle affluence groups. The subgroups for Norwegian women all exhibit positive improvements over the period. Interestingly, we see that the lowest affluence groups for Danish women actually see large improvements in life expectancy for the oldest ages, i.e. 80-95 year olds. We find that causes of deaths related to smoking are partly contributing to the slowdown in female longevity as low-middle and middle affluence groups display higher increases in death rates for smoking related causes of deaths. However the lack of improvements in deaths relating to ischemic heart diseases is dominant in explaining the slowdown as well as the following catch up effect in life expectancies. Regarding results for modelling and forecasts we find that reducing the size of the population subgroups has the advantage of removing substantial heterogeneity, while the model fit only decrease slightly. We find that using the aggregate country specific mortality data combined with socio-economic group data in the LL model improve the predictive ability compared with the LC model. Herein we find that the LL model produce the lowest forecast errors in 24 out of 39 cases.

The paper proceeds as follows. Section 2 introduces the unique datasets for Denmark and Norway, the affluence measure used and how the individuals are partitioned into subgroups

[1] See Cairns et al. (2016) and Section 2.1 for further discussion.

as well as the behaviour of these. Section 3 describes the model framework which is subsequently used to analyse the fit and forecast performance. Section 4 shows the estimation results, in-sample fit as well as a further analysis of the improvements across the subgroups and the decomposition of these improvements across different causes of death. Section 5 investigate the forecasting implications the single- vs multi-population models. Finally, Section 6 concludes.

2 Data and Indexation to Subgroups

The Danish register data, is drawn from Statistic Denmark and contains individual specific data for the years 1980-2012. The Norwegian register data is supplied by Statistics Norway for the years 1980-2008. Both registers contain information on yearly income, wealth, age, gender, year of death, municipality, highest obtained education level, and marital status etc. Focus is on advanced ages from 50 to 95 as both child mortality and adult mortality under the age of 50 have fallen dramatically; further improvements in life expectancy relies almost completely on mortality decline at old ages. [2]

The analysis is based on gender specific central death rates calculated from the Norwegian and Danish register data, given by

$$m(t,x) = \frac{d(t,x)}{E(t,x)} \tag{1}$$

$m_{t,x}$ is the central death rate at age x, at year end, in year t, $d_{t,x}$ is the number of deaths at age x in calender year t, and $E(t,x)$ is the exposure-to-risk at age x in year t. The exposure-to-risk is calculated as $E(t,x) = P(t,x) - d(t,x)/2$ where $P(t,x)$ is the population aged x on the 1/1 in year t. In the case of no migration this equals the central death rates calculated as $E(t,x) = (P(x,t) + P(x+1,t+1))/2$, see Lundstroem and Quist (2004) among others. Thus, as the migration is small these are approximately equivalent.

We use life expectancy as it is an intuitive measure which aggregates all age-specific death rates into a single measure. The life expectancy is calculated, using the assumption of a piecewise constant force of mortality, following Brouhns et al. (2002):

$$\bar{e}^{\uparrow}_x(t) = \frac{1-\exp\left(-m_{x,t}\right)}{m_{x,t}} + \sum_{k\geq 1}^{max(x)} \left(\prod_{j=0}^{k-1} \exp\left(-m_{x+j,t}\right) \right) \frac{1-\exp\left(-m_{x+k,t}\right)}{m_{x+k,t}} \tag{2}$$

Where $\bar{e}^{\uparrow}_x(t)$ is the period life expectancy (henceforth just life expectancy) for age x in year t.

As validation we compared the death rates and life expectancies of the total sex-specific population from Statistics Denmark and Statistic Norway with the data from Human Mortality Database (2015) and found the results to be almost identical.

The primary variables used for the affluence measure are the individual's income and wealth.[3] For Denmark gross annual income include all taxable income herein: wage income, unemployment insurance benefits, social security (from 1994), honoraria, all pension income and wage from being self-employed. For Norway the gross annual income variable

[2] Further, when partitioning the data into subgroups too few individuals is dying at the younger ages to conduct a proper analysis.

[3] See https://www.dst.dk and https://www.ssb.no for further infomation (in Danish and Norwegian)

includes gross wage income and compensation, income from being self-employed, gross pension, sickness benefits, unemployment benefits and child related benefits. The Danish and Norwegian household net wealth is defined as total assets minus total liabilities at year end. In Denmark the assets among others include real estate value, bank deposits, bonds, stocks, mortgage deeds, shares in firms, value of cars, boats and mobile homes as well as cash. The liabilities include credit secured by mortgage on real property, debt to financial institutions, debit/credit card debt, and all other types of debt to private companies and the government(e.g. unpaid tax or labour market contribution). For married couples the wealth is assigned by 50 % to each spouse. For Norway the main assets include real property, contents of the property, bank deposits, cash, stock, bonds and securities, other wealth from premium funds, pension agreement and the buyback value of life insurance as well as taxable wealth from abroad. We note that Statistics Norway do not allow for negative wealth or income.

For Denmark and Norway we make some modifications to the data where the most important are the following. In years with missing observations for an individual j we take the mean of the individuals income or wealth and assign it to the missing observation, adjusting for inflation. For Denmark we condition on positive observations when assigning this mean. For Denmark in the years 1980-1983 the wealth of a married couple in Denmark is assigned to the husband. For that reason we start the analysis in 1985 to avoid issues with poor data quality.

Indexation of Individuals into Subgroups

We divide the population into 10 subgroups based on a financial composite variable using income and wealth which we term the affluence index in the following. The indexation of individuals into ten subgroups is performed similar to Cairns et al. (2016) for both men and women in Norway and Denmark from which exposures, death counts and death rates are computed. The affluence index $A(j,t,x)$ for individual j aged x in year t is calculated as wealth plus k times the income in the preceding year, that is:

$$A(j,t,x) = W(j,t-1,x-1) + k \cdot I(j,t-1,x-1) \tag{3}$$

Where $W(j,t-1,x-1)$ is the wealth for individual j, at age $x-1$ in year $t-1$ and $I(j,t-1,x-1)$ is the income of individual j, at age $x-1$ in year $t-1$ and k is a constant. The procedure partitions the individuals into ten subgroups based on the rank of the affluence metric in the given year. We use data from the preceding year as wealth and income is either missing or measured with error in the year of death. We start the indexation in 1985, due to improved quality data from 1984 and onwards. We normalize all financial variables to be in real prices, 2000 levels. At the main retirement age of 67, each individual is locked to remain in the assigned group for the remainder of their spell. Different from Cairns et al. (2016), individuals aged 67 or older in 1985 is locked down to remain in the assigned group in 1985, instead of in 1981. This proves to be important for Danish women due to poor data quality of the wealth variable prior to 1984. The partition of individuals into subgroups is made conditioning on year, age, gender and marital status. We obtain death rates from age 51 as we use lagged variables for income and wealth.

Naturally we could use either wealth or income separately to partition individuals into subgroups. However, both variables provide important information about an individual's affluence level. The wealth and income variables will naturally be correlated as high income individuals tend to be wealthier, hence using a combination of the variables may be thought of as giving a more robust indexation if the variables are measured with noise. When combining the two financial measures it is important to account for size differences, hence the k times income specification. Based on the results in Cairns et al. (2016) we use $k = 15$ as it was found to be a good fit, even though the results was relatively robust to the choice. Moreover, intuitively 15 times income represent the approximate value of an individual's future retirement income, giving an estimate of the individuals 'total' wealth.

By disaggregating the Danish and Norwegian population into 10 subgroups we have achieved a very fine aggregation with fewer people in each group for the oldest ages. This naturally causes volatile behaviour for the oldest ages. We accommodate this by smoothing the data for all ages using splines following Wood (1994) prior to conducting the analysis.[4] Further, we are unable to distinguish between the two lowest affluence groups for the Danish women due to poor data quality. This leads us to lump the groups 1+2 into a single group now containing 20 % of the population. Mortality data for each of the subgroups will be made publicly available.

2.1 Descriptive Statistics

Table 1 contains descriptive statistics of the financial variables and demographic variables for Danish males and females. The mean and standard deviation are shown for income, wealth and the affluence index for each of the 10 groups. Further, it gives the share of people living in urban areas, being married, having obtained more than a high school education as well as the population count. We look at males and females separately as well as the ages 51-66 and 67-95 (non-pension and pension ages). Table 2 contain equivalent information for Norway. When comparing across gender and country in we take the average for the two lowest groups for Norway in order to makes the numbers comparable to the lumped group 1+2 for Danish women. All the financial variables are denoted in Danish Kroner (DKK) in year 2000 level.[5]

Naturally we see increasing values across socio-economic groups for all the financial variable for both countries. Women on average earn less and have less wealth than men. We also see that individuals above the retirement age in Denmark have lower income but higher wealth relative to income. This makes sense as older individuals are retired and they have had a longer period to accumulate wealth and pay of their mortgages. In both Denmark and Norway the standard deviation is higher for the more affluent groups compared to the middle and lower reflecting greater heterogeneity.
In Denmark the average income for women in group 10 is five times higher compared to group 1+2 (21 times in NO) below retirement age and three times higher (45 times in NO) above retirement age. Thus the income gap for women between the lowest and highest group is much higher in Norway. Similar results are seen for the men although the difference is slightly more pronounced in Denmark than in Norway.

The difference in wealth between groups for women in Denmark and Norway is significant both at working and retired ages. Again we note the significant increase in wealth in both countries when comparing group 9 and 10. These differences are found to be even more pronounced for men.

[4]The spline smoothing are performed using the Demography package by Hyndman (2010)

[5] The exchange rate to USD in year 2000 was 809.0294 DKK per 100 USD on yearly average. - Source Statistics Denmark (https://www.dst.dk)

Table 1: Income, wealth and affluence characteristics for each subgroup for the Danish men and women, shown for the ages 51-66 and 67-95 (non-pension and pension ages). The mean, standard deviation, number of observations as well as share of married, share living in urban areas and share with a higher education is shown for each group.

		Financial						Demographic			Count
		Income		Wealth		Affluence		Urb	Mar	Edu	
		Mean	SD	Mean	SD	Mean	SD	Share			
Grp 1	$F < 67$										
	$F \geq 67$										
	$M < 67$	89.7	38.3	134.8	233.7	1479.7	573.2	0.34	0.77	0.40	1345412
	$M \geq 67$	79.0	34.8	84.6	231.7	1269.3	606.6	0.36	0.66	0.18	717572
Grp 2	$F < 67$	71.4	41.8	172.3	245.0	1243.9	595.0	0.31	0.71	0.28	2753866
	$F \geq 67$	84.9	42.1	123.4	394.3	1396.6	803.2	0.41	0.34	0.10	2152859
	$M < 67$	148.0	45.2	207.4	293.7	2427.7	682.2	0.28	0.77	0.45	1345883
	$M \geq 67$	88.0	26.7	150.1	258.4	1469.4	499.2	0.33	0.66	0.20	750883
Grp 3	$F < 67$	116.4	43.3	230.7	270.6	1977.2	623.7	0.26	0.71	0.33	1377269
	$F \geq 67$	89.4	31.4	150.7	281.0	1491.1	599.6	0.37	0.33	0.10	1123110
	$M < 67$	179.5	52.4	276.8	329.9	2968.6	766.7	0.26	0.77	0.47	1345964
	$M \geq 67$	92.5	29.9	258.4	317.3	1646.5	564.6	0.27	0.66	0.21	782659
Grp 4	$F < 67$	137.2	48.0	286.6	299.8	2344.3	681.8	0.26	0.71	0.38	1377157
	$F \geq 67$	91.7	30.1	223.2	304.0	1598.7	592.4	0.31	0.33	0.10	1143447
	$M < 67$	203.0	56.1	363.4	378.4	3408.1	800.2	0.26	0.77	0.51	1345878
	$M \geq 67$	98.4	37.5	389.1	388.5	1864.6	696.1	0.24	0.66	0.23	810619
Grp 5	$F < 67$	157.3	52.0	339.0	339.7	2698.7	730.8	0.27	0.71	0.42	1377536
	$F \geq 67$	95.4	33.3	308.7	349.5	1739.3	660.1	0.28	0.32	0.12	1167487
	$M < 67$	227.6	59.3	446.1	436.7	3859.4	818.3	0.26	0.77	0.55	1346232
	$M \geq 67$	108.2	44.8	512.8	463.7	2135.1	814.4	0.23	0.66	0.24	829038
Grp 6	$F < 67$	177.6	55.9	393.7	387.3	3057.8	778.2	0.29	0.71	0.46	1376887
	$F \geq 67$	100.5	37.5	398.5	402.4	1905.9	738.4	0.27	0.32	0.14	1187693
	$M < 67$	254.3	62.4	532.6	499.4	4347.5	843.1	0.27	0.77	0.58	1345611
	$M \geq 67$	124.6	57.1	631.4	557.0	2500.7	1000.2	0.25	0.66	0.26	843620
Grp 7	$F < 67$	199.6	59.9	457.0	447.1	3451.5	831.4	0.31	0.71	0.52	1377355
	$F \geq 67$	108.9	43.5	501.6	486.0	2134.6	858.1	0.29	0.33	0.16	1204820
	$M < 67$	285.7	67.0	642.9	580.5	4927.9	892.5	0.29	0.77	0.63	1346042
	$M \geq 67$	145.9	71.2	764.8	664.5	2952.7	1249.1	0.27	0.66	0.29	856312
Grp 8	$F < 67$	225.5	65.2	544.9	523.7	3927.2	902.6	0.33	0.71	0.58	1377071
	$F \geq 67$	123.2	54.8	614.8	571.8	2463.5	1039.5	0.32	0.33	0.20	1220803
	$M < 67$	328.1	75.1	796.5	702.7	5718.0	985.6	0.30	0.77	0.68	1345800
	$M \geq 67$	173.1	88.8	944.5	798.6	3540.8	1574.1	0.29	0.67	0.32	876799
Grp 9	$F < 67$	259.9	72.2	715.6	659.8	4613.5	1015.0	0.35	0.71	0.65	1377364
	$F \geq 67$	149.3	66.3	813.8	755.9	3053.3	1296.9	0.37	0.33	0.24	1242635
	$M < 67$	399.7	94.2	1065.5	943.4	7060.8	1231.7	0.33	0.77	0.72	1346047
	$M \geq 67$	218.2	115.2	1260.7	1064.7	4533.0	2093.5	0.33	0.67	0.36	896134
Grp 10	$F < 67$	372.7	342.2	1765.6	6282.0	7356.3	8894.1	0.41	0.71	0.72	1376700
	$F \geq 67$	241.7	333.3	2110.4	14427.8	5736.4	16734.0	0.44	0.33	0.30	1271318
	$M < 67$	747.7	2080.2	2650.1	9402.5	13864.9	33915.4	0.35	0.77	0.74	1345412
	$M \geq 67$	418.2	811.3	3177.7	22835.1	9450.1	31111.9	0.39	0.68	0.43	919396

Table 2: Income, wealth and affluence characteristics for each subgroup for the Norwegian men and women, shown for the ages 51-66 and 67-95 (non-pension and pension ages). The mean, standard deviation, number of observations as well as share of married, share living in urban areas and share with a higher education is shown for each group.

		Financial						Demographic			Count
		Income		Wealth		Affluence		Urb	Mar	Edu	
		Mean	SD	Mean	SD	Mean	SD	Share			
Grp 1	$F < 67$	5.8	10.4	34.3	75.9	121.4	187.8	0.23	0.75	0.40	625845
	$F \geq 67$	0.6	8.0	1.1	18.0	9.9	126.2	0.27	0.37	0.29	673802
	$M < 67$	30.6	37.7	167.4	212.8	626.7	619.2	0.22	0.81	0.49	727633
	$M \geq 67$	33.8	68.6	82.1	157.3	588.9	1113.2	0.23	0.72	0.38	439117
Grp 2	$F < 67$	22.4	27.0	86.3	140.0	422.0	436.8	0.22	0.70	0.44	932712
	$F \geq 67$	4.7	21.6	18.4	109.4	88.4	366.6	0.27	0.39	0.31	755254
	$M < 67$	87.4	66.2	243.5	291.3	1554.8	1003.8	0.21	0.71	0.52	874862
	$M \geq 67$	52.0	76.5	192.3	247.5	971.6	1271.7	0.22	0.70	0.43	576042
Grp 3	$F < 67$	45.9	41.7	125.7	180.3	814.1	644.7	0.22	0.65	0.46	949761
	$F \geq 67$	9.9	29.2	50.7	143.0	199.7	508.4	0.26	0.37	0.32	819077
	$M < 67$	133.3	74.5	254.2	314.7	2253.5	1107.3	0.21	0.68	0.52	896715
	$M \geq 67$	61.5	77.5	272.6	354.7	1195.5	1324.3	0.21	0.67	0.45	618083
Grp 4	$F < 67$	73.8	50.4	160.6	209.4	1268.2	755.3	0.23	0.67	0.51	905147
	$F \geq 67$	15.5	33.6	87.7	201.9	320.0	602.3	0.25	0.37	0.34	863310
	$M < 67$	177.1	65.8	271.2	325.2	2927.1	956.3	0.22	0.72	0.56	866807
	$M \geq 67$	72.4	77.3	317.3	397.9	1403.7	1326.7	0.22	0.67	0.46	618640
Grp 5	$F < 67$	102.0	54.6	183.7	233.2	1714.4	801.7	0.25	0.68	0.55	878914
	$F \geq 67$	21.9	36.8	123.0	224.8	451.3	661.5	0.25	0.36	0.35	894008
	$M < 67$	210.4	58.4	288.1	332.2	3444.4	837.6	0.24	0.73	0.60	862198
	$M \geq 67$	84.3	76.6	323.5	406.1	1588.6	1298.9	0.22	0.67	0.45	619516
Grp 6	$F < 67$	129.7	56.5	195.9	250.6	2141.1	822.8	0.27	0.68	0.58	872309
	$F \geq 67$	30.7	41.0	158.5	276.3	619.6	736.4	0.26	0.36	0.38	915442
	$M < 67$	237.7	57.7	315.8	355.5	3881.8	832.0	0.26	0.73	0.65	871367
	$M \geq 67$	98.9	77.4	331.5	439.8	1815.5	1296.1	0.23	0.67	0.44	619047
Grp 7	$F < 67$	157.1	57.3	209.5	269.3	2566.1	833.4	0.31	0.68	0.63	875926
	$F \geq 67$	42.6	46.0	190.3	308.2	829.0	813.0	0.28	0.35	0.40	916737
	$M < 67$	265.4	61.7	362.2	405.8	4343.7	895.9	0.29	0.72	0.71	882756
	$M \geq 67$	115.8	80.7	345.9	437.7	2082.3	1332.0	0.24	0.67	0.46	624158
Grp 8	$F < 67$	186.4	57.6	231.7	296.5	3028.1	840.8	0.35	0.68	0.69	881812
	$F \geq 67$	57.5	52.7	221.8	340.2	1085.0	913.3	0.31	0.35	0.43	915925
	$M < 67$	300.6	71.7	433.9	494.8	4942.2	1044.6	0.33	0.72	0.78	889614
	$M \geq 67$	134.4	86.7	393.5	506.2	2409.1	1435.3	0.28	0.67	0.50	638653
Grp 9	$F < 67$	222.0	59.6	271.1	345.7	3600.6	874.3	0.40	0.68	0.77	891655
	$F \geq 67$	79.1	62.7	262.9	439.6	1449.0	1085.7	0.36	0.35	0.47	934873
	$M < 67$	358.6	95.5	566.3	685.3	5945.2	1401.0	0.39	0.72	0.85	890440
	$M \geq 67$	158.0	97.2	504.1	616.3	2874.6	1605.5	0.33	0.67	0.61	648275
Grp 10	$F < 67$	301.5	142.8	661.8	5057.7	5184.1	5471.9	0.51	0.68	0.89	904529
	$F \geq 67$	123.4	94.1	537.6	2733.7	2388.0	3129.2	0.45	0.34	0.63	959351
	$M < 67$	597.4	804.8	1871.1	14844.5	10832.4	20579.9	0.50	0.72	0.91	888688
	$M \geq 67$	246.4	834.2	1355.1	15587.8	5051.9	23534.8	0.45	0.67	0.79	669513

The affluence measure maintains the ranking across the 10 groups by construction, as was also found for income and wealth. Below the age of 67 the affluence measure is seven times higher (ten times in NO) for men and six times higher (18 times in NO) for women when comparing group 1+2 with group 10. Above the retirement age, the affluence measure is four times higher for Danish women and 50 times higher for Norwegian women, while for men the affluence measure is seven times higher for both countries.

Finally, we summarize the demographic statistics for the 10 socio-economic groups including urbanization, marital status, as well as level of education. The urbanization variable is defined as the share of individuals living in the cities (more than 150.000 inhabitants). For Denmark these include Greater Copenhagen, Aarhus, Odense and Aalborg and in Norway, Greater Oslo, Bergen, Stavanger/Sandnes and Trondheim is included. The urbanization variable show similar rates for men and women but with a slightly higher urbanization rate for women. Further the lower and middle affluence groups show similar shares of urbanization of around 25 %, but the urbanization share increases substantially for the highest affluence groups reflecting that high income jobs as well as housing wealth tend to be concentrated around the cities. A similar pattern is found for both countries.
Marital status is described by the share of married individuals. As we condition on marital status when indexing into subgroups the groups are expected to show similar shares. Differences reflect variations in the mortality pattern of married versus unmarried individuals over the period. We see that men in general are more likely to be married independent of the two considered age group. The gender gap is especially pronounced for individuals above the retirement age as around 70 % of males above the age of 67 is married compared to 35 % for females. Explained by women on average living longer hence being more likely to become widows. We see a strong increase in the share of married individuals across socio-economic groups which make sense as wealthier individuals on average live longer and are more likely to be married. Further, married individuals also benefit from significant lower mortality rates explained in the literature by two main reasons. One attributes the effects of selection of low-risk individuals into the marriage state and another to the protective effects of marriage, see among others Hu and Goldman (1990).

The education variable shows that men at the considered ages and year are more likely to have completed high school compared to women, this pattern is especially pronounced for the ages older than 67. Individuals below retirement age are more likely to have an education level beyond high school diploma reflecting an increase in the general level of education for the whole population over the period. Naturally within a given cohort the education level will be stable at the considered ages, but looking over time and across the ages the education level have been rising which may distort the developments in life expectancy over time. For instance the lowest education in 1985 would contain a substantially larger share of the population compared with 2012. Hence, there is an increasing concentration amongst the least well of individuals in the lowest education group over time. This selectivity might introduce a downward bias in life expectancy as one is increasingly considering the worse off individuals whereas the more well of individuals would now be part of a higher education group. This is in contrast to the affluence groups which ensure 10 % in each affluence group for each age and year.[6] Moreover it is important to note that a lower share of higher educated individuals is found for individuals older than age 67 in Denmark due to the fact that level of education is only reported for individuals born after 1922, i.e. younger than age 63 in 1985. Finally, we see that the share of individuals with higher education is increasing across socio-economic groups reflecting that high earners tend to be better educated. For

[6]These issues with education as a discriminator is also discussed in Cairns et al. (2016).

individuals below the retirement age the shares double when comparing the lowest affluence groups to the highest.

2.2 Empirical Analysis

Before modelling the mortality behaviour we illustrate the observed period of divergence in life expectancy observed for women in the two countries. The divergence is not observed for men. It is seen in Figures 1a and 1b that the divergence begins around 1980 and continues until 1995. Outside this time period the Danish and Norwegian women follow a similar pattern. Danish women's life expectancy decline from 28.85 years in 1980 to 28.82 years in 1995 compared with an increase in life expectancy for Norwegian women from 30.10 years to 31.25 years. Thus, the gap in life expectancy increases almost 1.2 years over a 15 year time period.

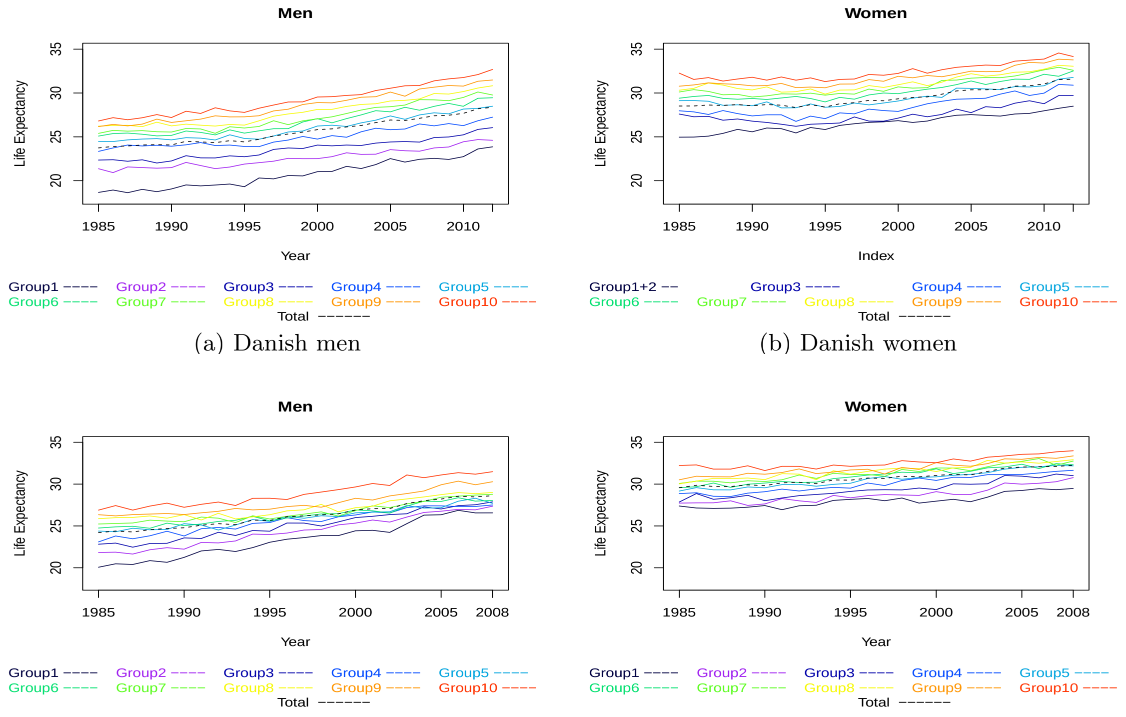
(a) Men (b) Women

Figure 1: The life expectancy for the gender specific total population at age 51, based on the Human Mortality Database for Danish and Norwegian

Behaviour of the Subgroups

In the following we decompose the population into subgroups which in term gives a clearer picture of how the divergence emerged. Figure 2 illustrate how the life expectancy at age 51 develop for each socio-economic subgroup for men and women in Denmark and Norway. The life expectancy is found to be regularly increasing over time and with affluence in both countries. For Danish women we clearly observe the standstill and for the low-middle and middle affluence groups even a decrease in life expectancy from 1985 to 1995 in figure 2b. This is not seen for either men or Norwegian women who increase more or less regularly over the full period. We observe differences in life expectancy of up to 7-8 years for 50 year old males and 5-6 years for 50 year old females in the mid-1980s and significant differences throughout the period. Hence, we find that the social inequality in mortality is greater for men than for women confirming the results of several former studies, see Marmot and McDowall (1986), Koskinen and Martelin (1994), Mackenbach et al. (2003), and Brønnum-Hansen and Baadsgaard (2012).

The clear ranking of life expectancies across subgroups persist across ages although the differences between the subgroups decrease with age and the pattern become slightly less clear, see Appendix A for the ages 70 and 90. For all affluence groups the female life expectancy is higher than for the related male group, hence exhibiting the regularity from the total population. However, men experience larger increases in life expectancy compared to women and thus partly catches up in terms of life expectancy in both Denmark and Norway.



(a) Danish men (b) Danish women

(c) Norwegian men (d) Norwegian women

Figure 2: The life expectancy for the affluence groups 1-10 at age 51, for Danish and Norwegian men and women for the period 1985-2008/2012

3 Model Framework

In order to assess the importance of using socio-economic information we model and predict the subgroups separately to evaluate the performance compared to the overall population. We use two different models in the analysis. Firstly, the well known Lee and Carter (1992) model and secondly the coherent model by Li and Lee (2005). The latter allows us to investigate whether information from the overall population combined with the group-specific population improves the forecasting performance. Compared with the typical applications of multi-population models which use different countries, we expect that our approach will imply greater coherence as the subgroups are all exposed to the same welfare state, health care sector, etc.

3.1 The Lee-Carter Model

The Lee and Carter (1992) model, describe the age-specific death rates by

$$\ln m_{x,t} = \alpha_x + \beta_x \kappa_t + \varepsilon_{x,t} \tag{4}$$

where α_x is a constant describing the general death rates for each age x, i.e. the time-average of the log death rates. κ_t is a time varying factor capturing the overall trend in death rates over time t. β_x is the factor loading, governing the effect of the factor κ_t on the ages x. Hence, ages with a high β_x will change more with κ_t. Further, $\varepsilon_{x,t}$ is the age and time specific error not captured by the model. We use the normalizations $\sum_{x=x_1}^{x_m} \beta_x = 1$ and $\sum_{t=t_1}^{t_n} \kappa_t = 0$, similar to Lee and Carter (1992). α_x is estimated as the time-average of the log death rates $\ln m_{x,t}$, for each age x. β_x and κ_t are then estimated using the singular value decomposition on the matrix $A_{xt} = \ln m_{xt} - \alpha_x$ for each x, t. Next, we refit κ_t such that the fitted and observed life expectancy match, see Lee and Miller (2001). Finally, the time-varying factor κ_t is predicted using a random walk with drift which is the general consensus in the literature, see e.g. Lee and Miller (2001) and Booth et al. (2002, 2005).

3.2 Coherent Mortality Forecasts for a Group of Populations

Different approaches for incorporating information from multiple populations have been proposed. We use the Li and Lee (2005) (LL) model which propose a simple extension of the LC model accounting for coherent effects. Naturally, other models incorporating information from multi-populations could be considered, such as the CBD-X model, see for instance Cairns et al. (2016) and Dowd et al. (2011). Intuitively the idea of the LL model is that some populations might differ in terms of life expectancy but still expose a stable relation over time. Li and Lee (2005) model the coherent relation by extending the LC model with a common component $B(x)$ and $K(t)$ which is estimated for the overall population, using the LC model. Having obtained the common factor and corresponding loading, the LL model for each subpopulation i is given by:

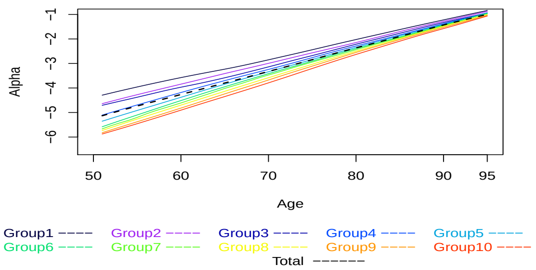
$$\log m_{i,x,t} = \alpha_{i,x} + B(x)K(t) + \beta_{i,x}\kappa_{i,t} + \varepsilon_{i,x,t} \tag{5}$$

Where $\alpha_{i,x}$ is the population specific average death rate and $\beta_{i,x}$ and $\kappa_{i,t}$ is the population specific estimates of the factor and loading estimated by SVD. $\varepsilon_{i,x,t}$ is the model error for population i at age x in year t. An important condition for the approach is that $\kappa_{i,t}$ should not drift away. This is accommodated by using a stationary AR(1) for $\kappa_{i,t}$, which avoid long-run divergence in mortality between the different populations. Again $K(t)$ is predicted using a random walk with drift such that the time trend in mortality is captured by the overall population.

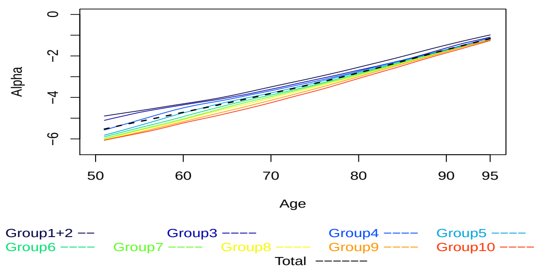
4 Empirical Results

4.1 Estimation Results

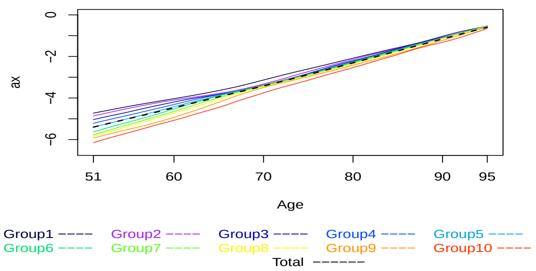
This section shows the parameter estimates for each of the ten subgroups as well as the total population for the LC and LL model. The α_x estimates, which are identical in the LC and LL model are shown in Figure 3 for both countries and genders. We see that the death rates are increasing with age for all affluence groups but decreasing across groups with the highest affluence group having the lowest mortality as would be expected. There is a clear pattern of convergence between death rates for the ten groups with age becoming almost identical for the oldest ages. This group-specific convergence with age is found for both genders and countries, however being slightly more pronounced for Norway. The convergence in mortality for old-ages corresponds well with research on late-life mortality convergence also called the compensation law of mortality, see among others Gavrilov and Gavrilova (1979, 1991, 2006), Strehler and Mildvan (1960) and Avraam et al. (2014). This convergence with age is also found for the USA in e.g. Cristia (2009).



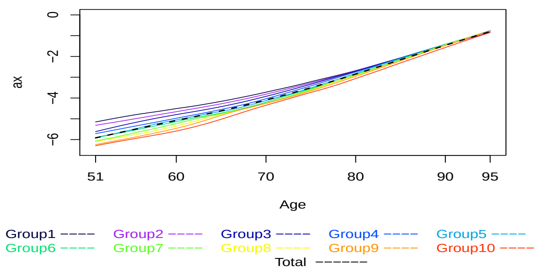
(a) Danish, Men



(b) Danish, Women



(c) Norwegian, Men

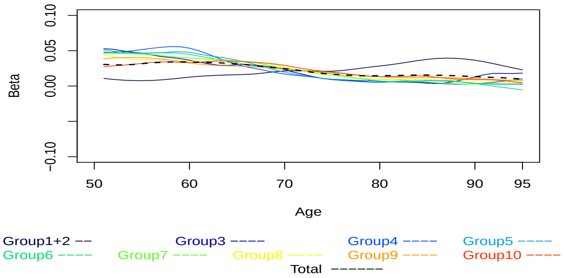


(d) Norwegian, Women

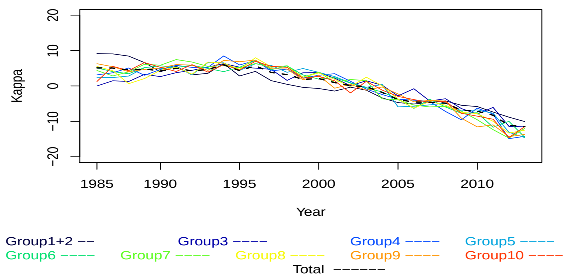
Figure 3: The α_x estimates for both genders for Denmark and Norway, for each of the ten affluence groups using the LC model.

We now show the β_x and κ_t estimates from the LC model in Figure 4 and in Figure 5 for the LL model. The parameter estimates for men is left for Appendix B. Note that the estimates for the total population trend and age effects $K(t)$ and $B(x)$ of the LL model and LC model are shown by the dotted lines in the Figure 4 for the LC model. The overall population time trend $K(t)$ in the LC (LL) model exhibits a clear linear trend for Norway, but for Danish women we observe a clear break around 1995 reflecting the change in the mortality pattern.

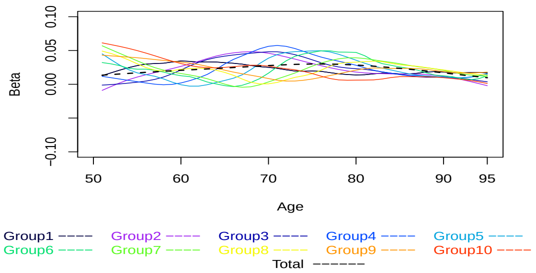
The subgroup parameters are slightly more volatile compared to estimates based on the total population as they capture different subgroup trends and are based on smaller sample sizes. This is especially pronounced for the β_x's. The larger gains in life expectancy for the oldest Danish females in group 1+2 (compared to the younger females in these groups) manifest itself very clearly in β_x estimates in figure 4a. All other groups show higher gains for younger Danish females. In Norway the pattern for the β_x is less clear but a convergence in gains across ages is observed. From the estimates of κ_t for Danish women we get a first indication that certain groups deviate from the other groups in the first part of the sample period. In particular, Danish women in groups 3-5 did not experience any improvements in life expectancy captured by the increasing κ_t over the years 1985-1995. All other groups exhibit a relative constant κ_t until 1995. Thereafter, all subgroups for Danish women resume the standard downward sloping trend. For Norwegian women a much clearer downward sloping trend is observed for all groups over the entire time period.



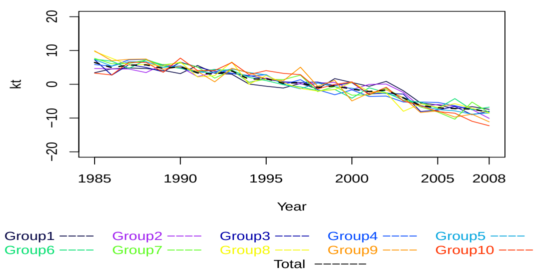
(a) LC β_x Danish women



(b) LC κ_t Danish women

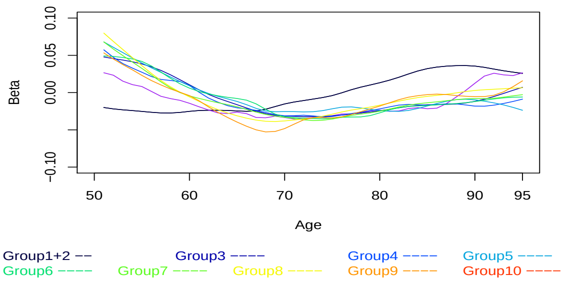


(c) LC β_x Norwegian women

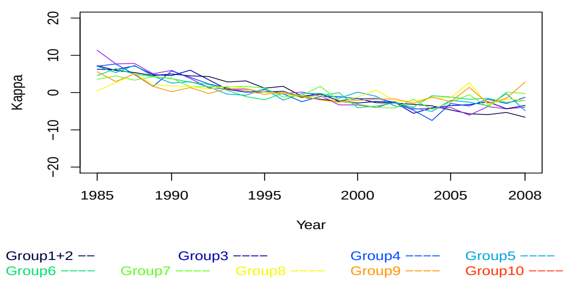


(d) LC κ_t Norwegian women

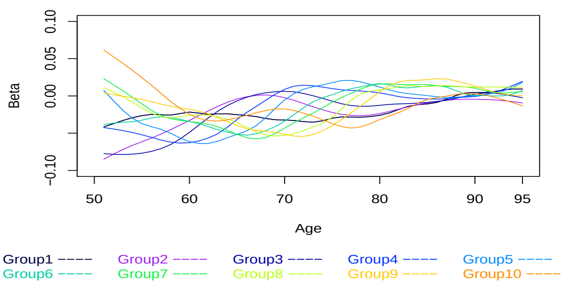
Figure 4: The β_x and κ_t estimates for women in Denmark and Norway using the LC model, for each of the ten affluence groups.



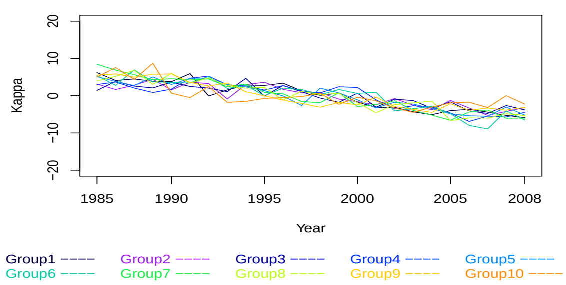
(a) LL β_x Danish women



(b) LL κ_t Danish women



(c) LL β_x Norwegian women



(d) LL κ_t Norwegian women

Figure 5: The β_x and κ_t estimates for women in Denmark and Norway, for each of the ten affluence groups in the Li-Lee model.

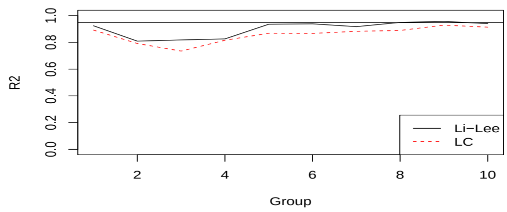
For illustration purpose we normalize $\beta_{i,x}$ in Figures 5a and 5c such that the sum of its absolute values equal one.[7] The $\beta_{i,x}$ and $\kappa_{i,t}$ show a less clear pattern for the LL model compared with the LC model which is to be expected as they only captures what is left of the variation after removing the overall trend. In Figures 5b and 5d we see that the $\kappa_{i,t}$ take on smaller values and do not exhibit as strong a break in the year 1995 for Danish women, indicating that the common factor accounts for a large part of the variation.

In-Sample Fit

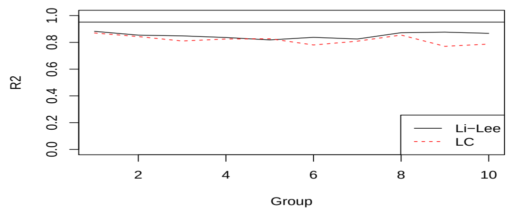
We compare the in-sample fit of the LC and the LL models for each of the subgroups to see how the fit perform relative to the overall population as well as between the models. To measure the model fit, we calculate the R^2 for each subgroup using:

$$R^2 = 1 - \frac{SSE}{SST} = 1 - \frac{\log m_{x,t} - \log \widehat{m_{x,t}}}{\log m_{x,t} - log\bar{m}_x} \tag{6}$$

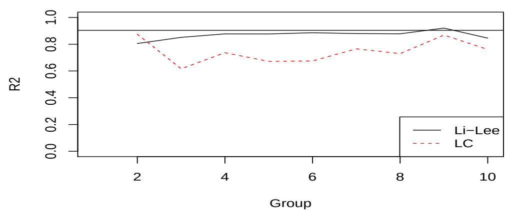
The R^2 for each subgroup and the total population(straight line) is shown in the Figures 6a to 6d for men and women in Denmark and Norway for the LC and LL model.



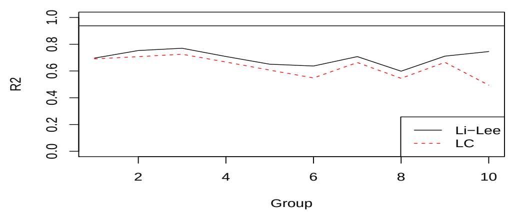
(a) R^2 for Danish men using the LC and the LL model.



(b) R^2 for Norwegian men using the LC and the LL model.



(c) R^2 for Danish women using the LC and the LL model.



(d) R^2 for Norwegian women using the LC and the LL model.

Figure 6: Gender specific R^2 for each of the subgroups using the LC and LL model. For the LL model we also show the gain from the group specific factor by showing the fit of the common factor model.

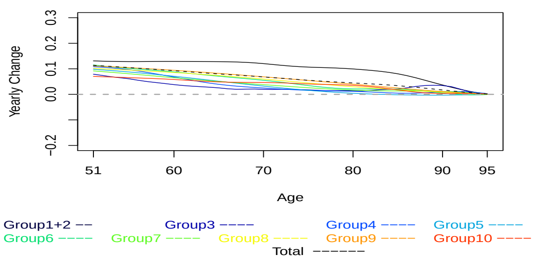
We find that the in-sample fit naturally decreases by a small amount for the subgroups, due to the variability from having only a tenth of the population size. Comparing the fit across groups the higher affluence groups are found to perform significantly better indicating larger

[7] The absolute values is used as $\beta_{i,x}$ tend to take both signs, which would inflate the size of the $\beta_{i,x}$'s if these where to sum to one as assumed by the model.

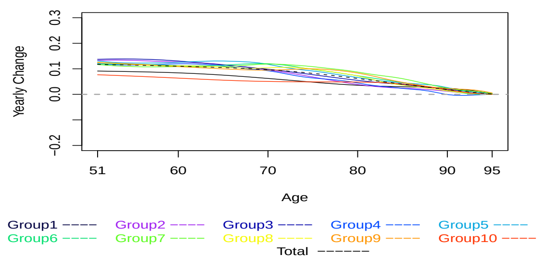
volatility within the lowest affluence groups. Further, we find that the LL model tend to perform better in terms of in-sample fit relative to the LC model as we augment this with a factor for the overall population. We also tested the common factor model of Li and Lee (2005) and found that the LL model performs substantially better indicating that the subgroup specific factor is needed to provide a good fit for the subgroups.

4.2 Yearly Changes in Life Expectancy

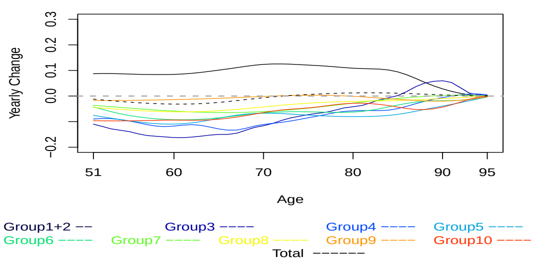
The κ_t estimates of the LC model gave some indication that the low-middle and middle affluence groups have experienced limited improvements in the time period 1985-1995. By examining improvements in life expectancy in Figure 7 we try to extract information about the diverging and converging periods in female life expectancy.[8]



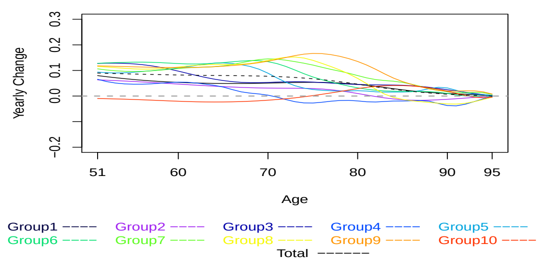
(a) Danish women 1985-2012



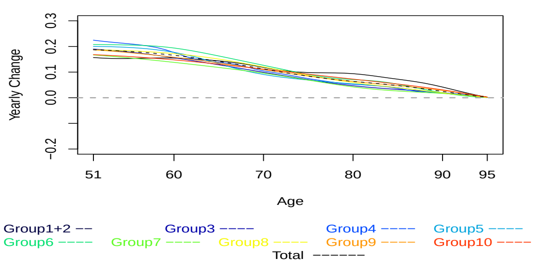
(b) Norwegian women 1985-2008



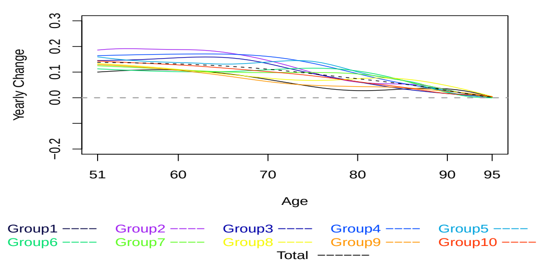
(c) Danish women 1985-1995



(d) Norwegian women 1985-1995



(e) Danish women 1995-2012



(f) Norwegian women 1995-2008

Figure 7: Average yearly changes in life expectancy for women in Norway and Denmark for the full period as well as 1985-1995 and 1995-2008/2012.

[8] An alternative option is to look at the yearly average percentage improvements however this will imply very large changes for older age groups (or the least affluent groups) with low initial life expectancies compared to younger age groups (or the more affluent groups) with high initial life expectancies and thus distort the general picture for improvements in life expectancy.

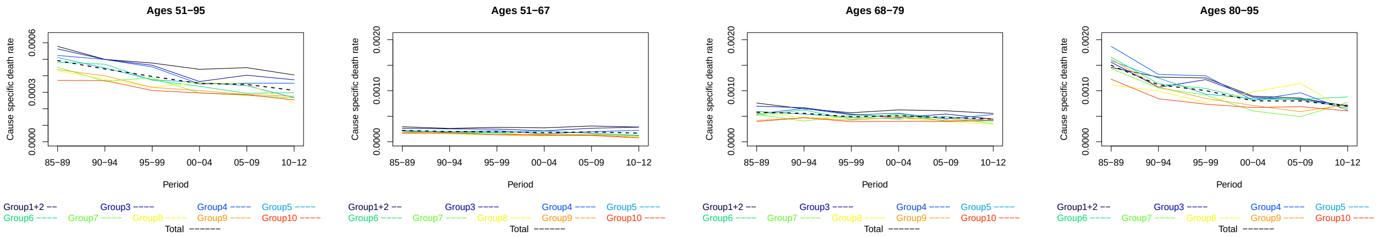
The yearly improvements in life expectancy for women aged 51-95 in Denmark and Norway are shown in the Figure 7 for the full time period, the years 1985-1995 and 1995-2012. The corresponding plots are shown for Danish and Norwegian men in Figure 19 in Appendix C. Looking at the Figures 7a and 7a for the full period a number of points become apparent. Firstly, the yearly increases in life expectancy is found to be larger for the younger compared to older individuals. This pattern is consistent for all groups and both genders with the exception of the two lowest affluence groups for Danish women which show large increases in life expectancy for the ages around 80-95 years old. Secondly, for Danish females in Figure 7a the low-middle and middle affluence groups are lagging behind in terms of improvements, which clearly is not the case for Norwegian women in Figure 7b. Thirdly, the men experience larger gains in life expectancy compared to women as seen in Appendix C.

Looking at the first and second period separately in the Figures 7c to 7f we obtain the following insights. Firstly, the downward sloping trend of improvements in life expectancy across ages no longer appears for Danish women in the time period 1985-1995. This pattern seems to be reversed in the first part as seen in figure 7c. All groups for Danish females (with the exception of group 9) decline over the first part. In particular, it is found that the largest decline in life expectancy for Danish women primarily occurs for the groups 3-7, in particular 3-5, illustrating that it is not driven by either high or low affluence groups. Thus, the low-middle and middle affluence groups are driving the slowdown. Secondly, we note that all the groups for Norwegian women show increasing life expectancy for both periods. Thirdly, the large improvements for the 80-95 year old Danish women in the groups 1+2 are due to the huge improvement over the first part of the period and not the second part of the period. Had group 1+2 not seen the large improvement for the 80-95 year olds, then the decline in female life expectancy in Denmark during the time period 1980-1995 would have been even more pronounced. Finally, in figures 7e and 7f we observe that all the groups in both countries revert to the same positive downward sloping pattern in life expectancy improvements with age with little dispersion between the ten groups. In particular we see a catch up effect for the low-middle and middle affluence groups as these groups experience the largest gains in life expectancy for 50-70 year olds after 1995.

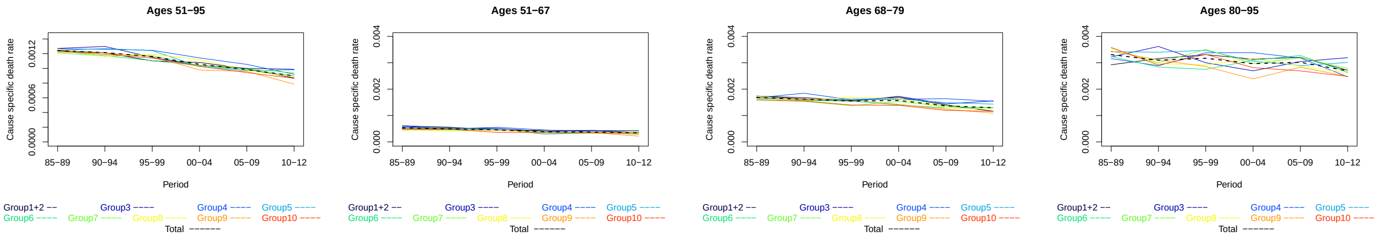
4.3 Causes Specific Death Rates for Danish Women

Having identified which socio-economic groups are causing the slowdown in the 80s and early 90s, triggers the question: Why these low-middle and middle affluence groups, and not the low or high affluence groups? By combining socio-economic group information with cause of death (COD) data we can use the observed heterogeneity and its development over time to get a clearer view of which causes of death are behind the observed divergence followed by convergence. We only display cause of death data for Danish women and leave the results for Danish men to the appendix.[9] The cause of death data has been classified into 27 general causes of death using both the ICD-8 (up to 1994) and ICD-10 (from 1995) classification. We then calculate the cause specific death rate for each of the 27 causes of deaths in each of the 10 affluence groups. We group the years into the intervals 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12. Moreover we consider all ages together as well as the three separate age groups; 51-67, 68-79 and 80-95 in order to understand the development in the mortality pattern in different life stages. The outcome is displayed in the Figures 8 to 12 where we note that the y-scale is only comparable for the age specific death rates within the given cause of death.

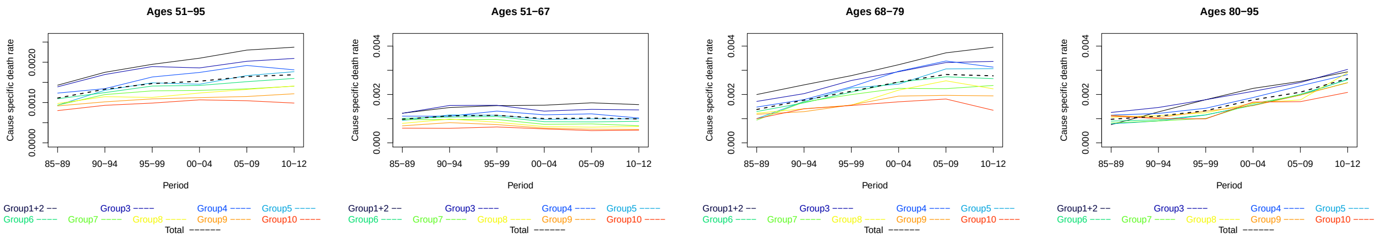
[9] We have not been able to obtain cause of death data for Norway.



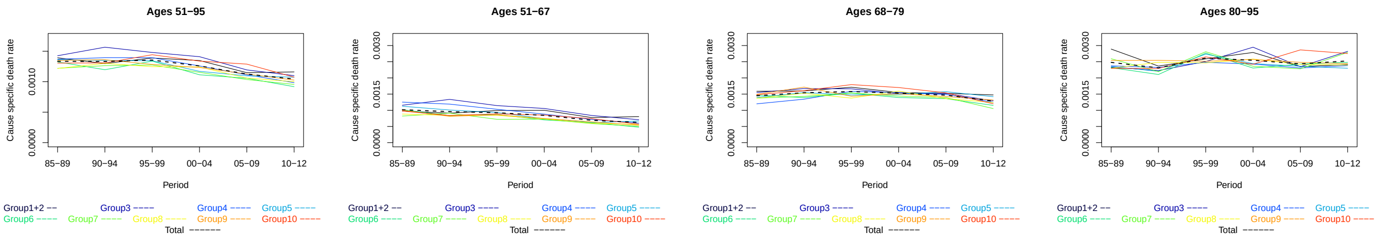
(a) Cancer in mouth, gullet and stomach



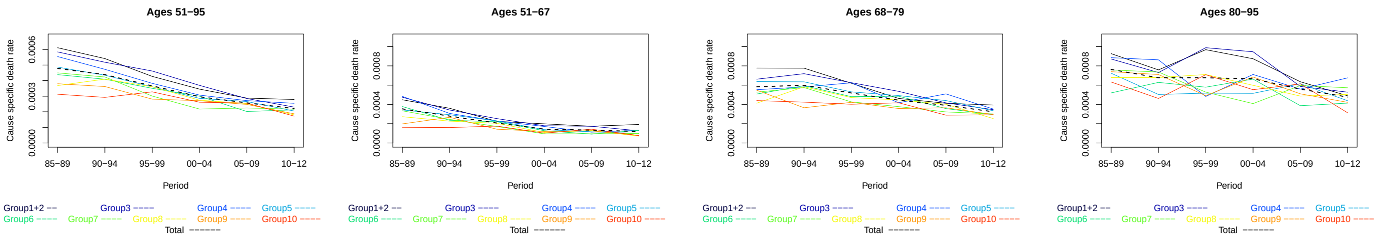
(b) Cancer in gut or rectum



(c) Cancer in larynx, trachea, bronchus or lungs

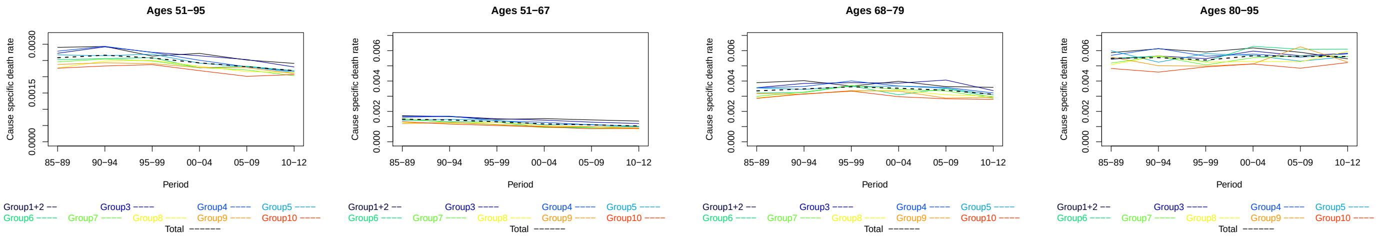


(d) Breast Cancer

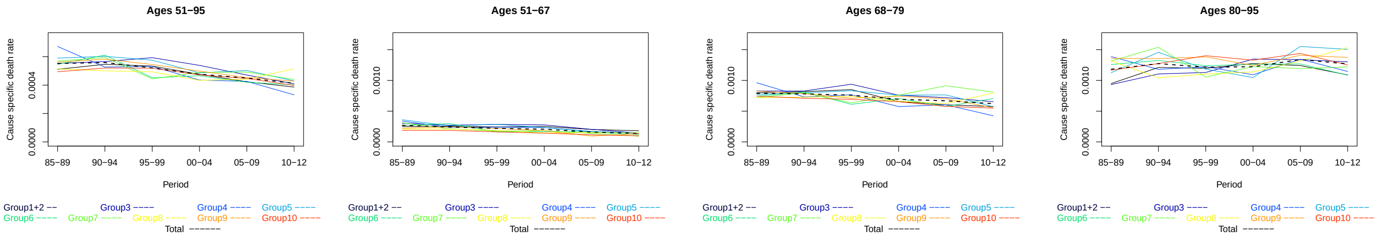


(e) Cancer in uterus and cervix

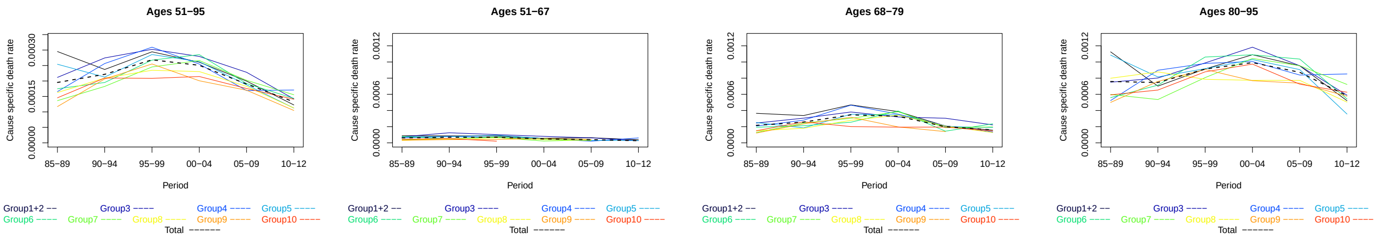
Figure 8: Cancer related cause of death rates for Danish women in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



(a) Cancer in bones, skin or other unspecified locations.



(b) Cancer in lymphatic or blood-forming tissues



(c) Benign tumours or tumours without specification.

Figure 9: Cancer related cause of death rates for Danish women in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12

It is clear that many different patterns have emerged; some causes display an increased social gradient over time, some a decreasing gradient, some no distinct socio-economic gradient, and some a consistent gradient. Generally, we see that for most of the causes the clear ranking between the socioeconomic groups persists. Moreover we see different patterns emerging across ages. It is found that all causes of death, with the exception of cancer in larynx, trachea, bronchus or lungs, show an increasing death rate with respect to age.[10] To gain further insight into why certain socio-economic groups have experienced a slowdown we are interested in cases where the low-middle and middle affluence groups for women performed poorly compared to the other groups in the time period 1980-1995 but not in later periods.

Previous studies have explained the general lower life expectancy in Denmark compared to the other Scandinavian countries with smoking-related deaths, see Jacobsen et al. (2006) and Juel (2008). In Figure 8c we see a clear social gradient for cancer in larynx, trachea, bronchus and lungs however there is no tendency to this being eliminated over time.[11] On the contrary, the gap is increasing and this particularly pronounced for the ages 68 to 79.

[10]For lung cancer the median age of diagnosis is often found to be between age 64 and 70, see Maione et al. (2010) and Owonikoko et al. (2007). It is found by Jemal et al. (2010) that the 5-year survival probability is about 16 %. Thus these individuals are unlikely to survive to very old age.

[11]It is estimated that worldwide, tobacco smoking accounts for 71 % of all trachea, bronchus, and lung cancer deaths, see Mackay et al. (2006).

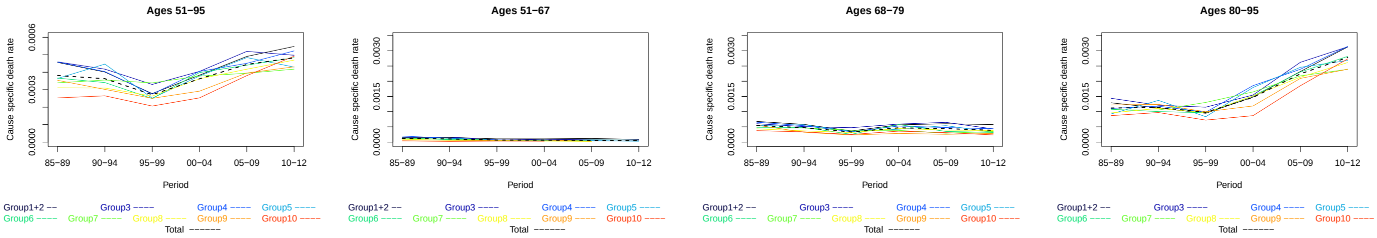
We see that for this age group, females in the low-middle and middle affluence groups have experienced higher increases in death rates compared to the other groups. This is not the case for males as seen in the appendix.

Another cause of death related to smoking is lung and breathing diseases shown in Figure 10f. Again, we see that the gap between the affluence groups is increasing over time mainly driven by significant higher death rates for the low-middle and middle affluence groups. In particular we note how affluence group 1+2 is at a complete standstill throughout the whole period. Studies also suggest that smoking is an independent risk factor for the development of diabetes and that smokers in fact are 30–40 % more likely to develop type 2 diabetes than nonsmokers Warren et al. (2014). In Figure 11b we see that cause-specific death rates for diabetes have slightly increased over the time periods. This increase is driven by the older part of the population and from the fact that the low-middle and middle affluence groups have experienced increases in death rates in the first time part which are much higher compared to the other groups. The final cause of death that displays an increasing gap over time between the affluence groups is infection diseases and tuberculosis (Figure 11e). A new study show that smoking doubles the risk of recurrent tuberculosis, see Yen et al. (2014), and thus this smoking related disease follows a similar pattern to the above described causes of death without the higher increases for the low-middle and middle affluence groups.

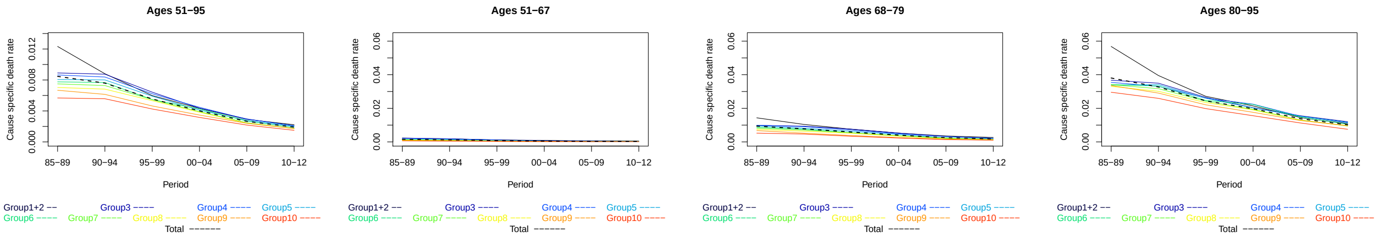
Finally, smoking has been attributed to account for 14 % of deaths from heart and circulatory disease, see Health and Social Care Information Centre (2012). Compared with non-smokers, smokers have a 2 to 4 times increased risk of heart disease and of stroke, see US Department of Health and Human Services and others (2004). A study by Huxley and Woodward (2011) also found that the risk of coronary heart disease is 25 per cent higher in female smokers than in male smokers. From Figure 10b we see significant improvements for the ischemic heart diseases over time for women (a similar pattern is observed for men, see Appendix D). The time period 1985-1995 is dominated by very limited gains for females in the low-middle and middle affluence groups contrary to other groups as well as all male groups (see Appendix C). Moreover we note the strong gains observed for the combined (group 1-2) low affluence group. This pattern is particularly distinct for the very old. After 1995 we see consistent improvements for all affluence groups and ages however with the gains being more pronounced for the very old. This structural change is likely caused by the introduction of the 'Heart Plan' health initiatives in Denmark in 1993, see Kjøller et al. (2007). It aimed to increase the capacity at the departments of Cardiothoracic and Vascular Surgery by doubling the capacity which allowed high risk patients to receive treatment within 1-2 weeks after their first medical examination. The number of angioplasty and bypass surgery increased from below 1000 in 1993 to around 12000 in 2004, see Kjøller et al. (2007).[12] This policy change has had a tremendous effect and the social gradient that previously existed for heart diseases is almost completely eliminated.

Two other causes of deaths related to diseases of the circulatory system that have displayed a similar pattern are cerebrovascular diseases shown in Figure 10d and circulatory diseases shown in Figure 10e. We see that females in the low-middle and middle affluence groups have experienced the highest increase in death rates in the time period 1985-1995 and again the pattern is more distinct for the older females. After 1995 the cause specific death rates improves for all affluence groups in a homogeneous way. To some extent we see a similar pattern for males in the Appendix. These three causes of deaths related to the circulatory

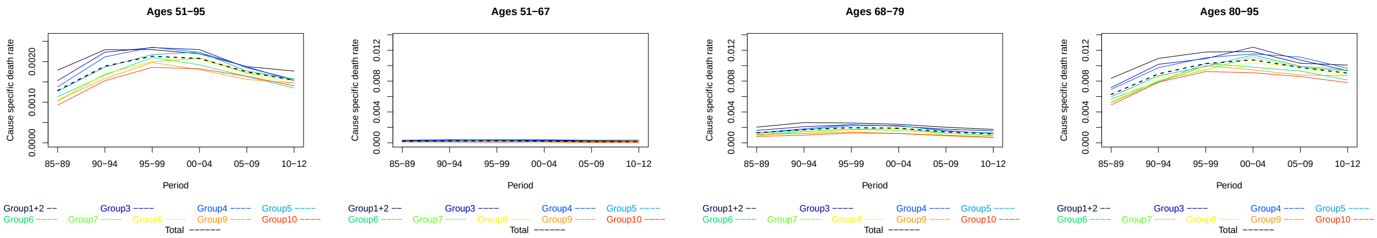
[12] Moreover, at the same time the 'Free Hospital Choice' was introduced to reduce the waiting period for treatment on all diseases by allowing the individual to receive treatment in a different region if their local hospital was unable to offer it within a pre-specified time frame, see Kjøller et al. (2007)



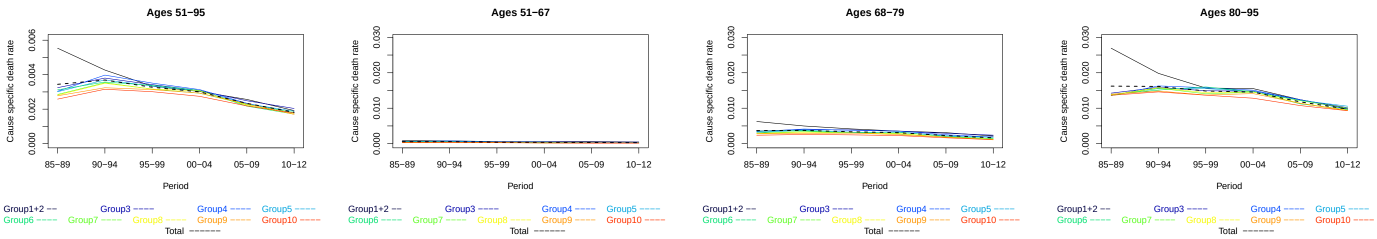
(a) Increased blood pressure or rheumatic fever



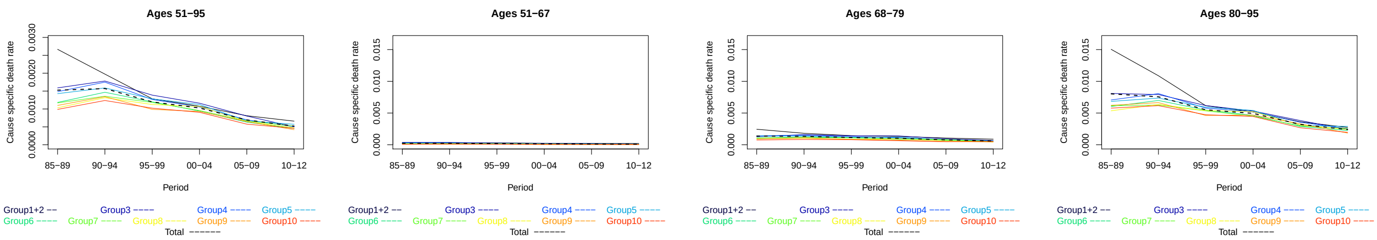
(b) Ischaemic heart diseases



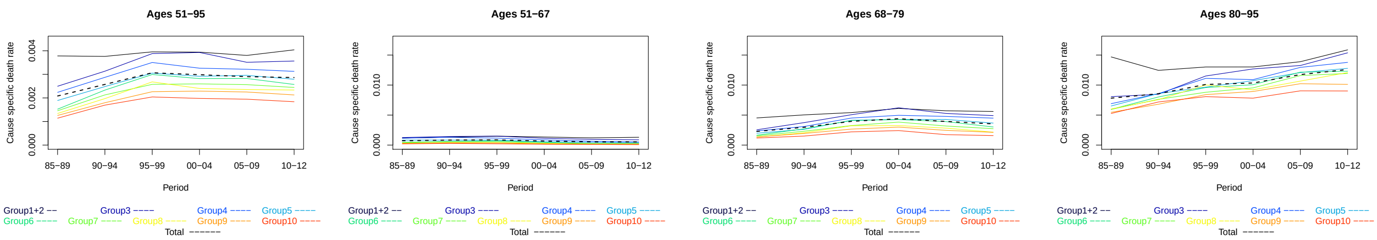
(c) Other heart diseases



(d) Cerebrovascular disease

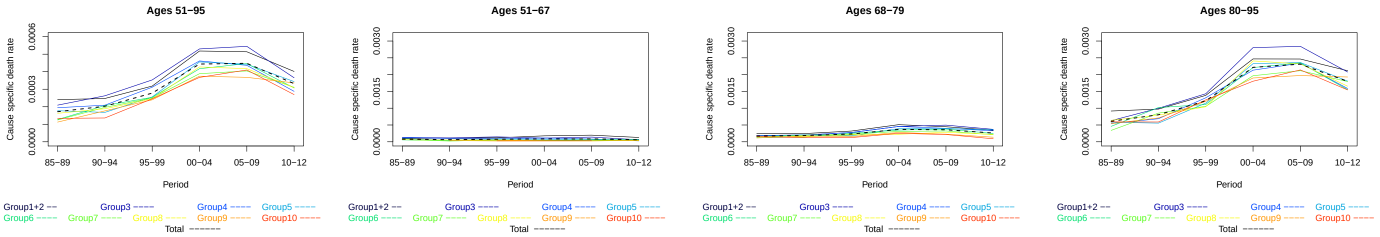


(e) Circulatory diseases

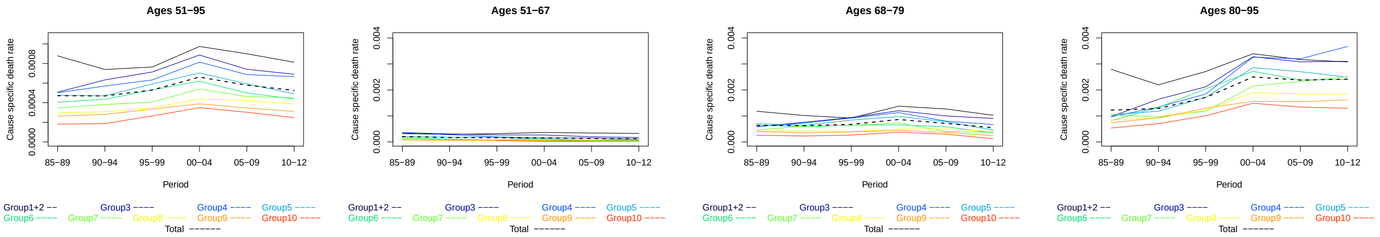


(f) Lungs and breathing diseases

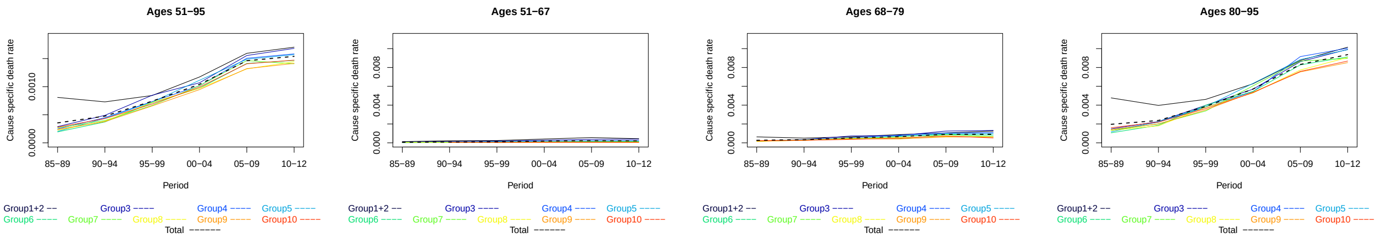
Figure 10: Cause of death rates for Danish women in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



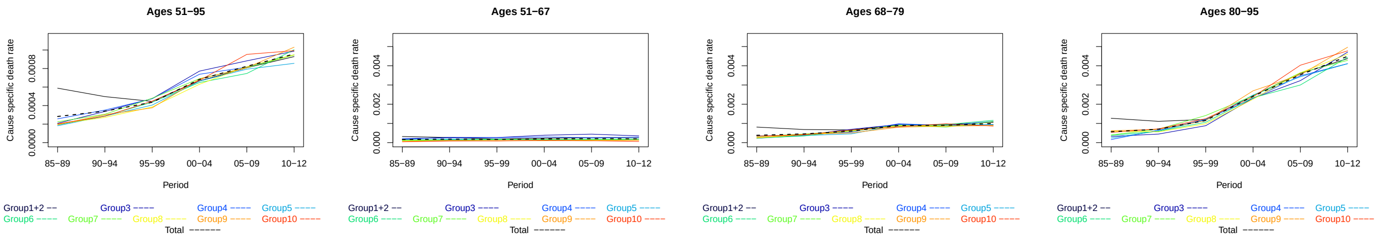
(a) Diseases in blood and blood forming organs, as well as endocrine sufferings and deficiency diseases.



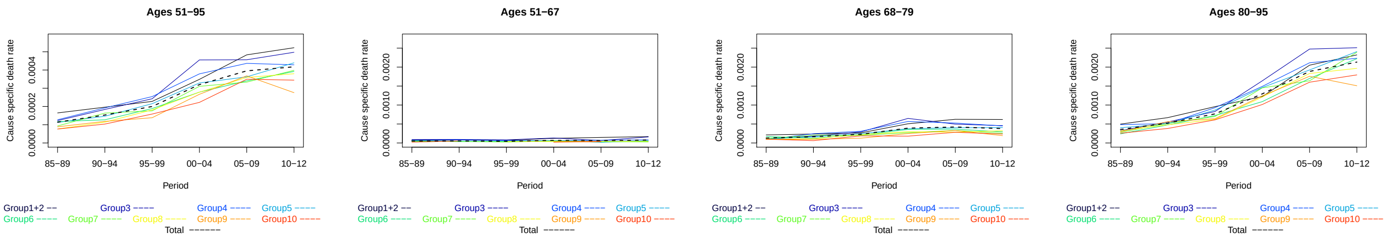
(b) Diabetes



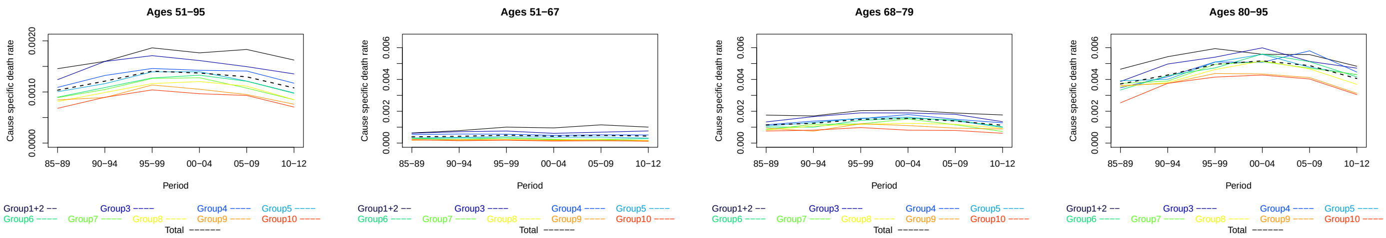
(c) Mental illnesses



(d) Meningitis and diseases in the nervous system as well as sense organs.

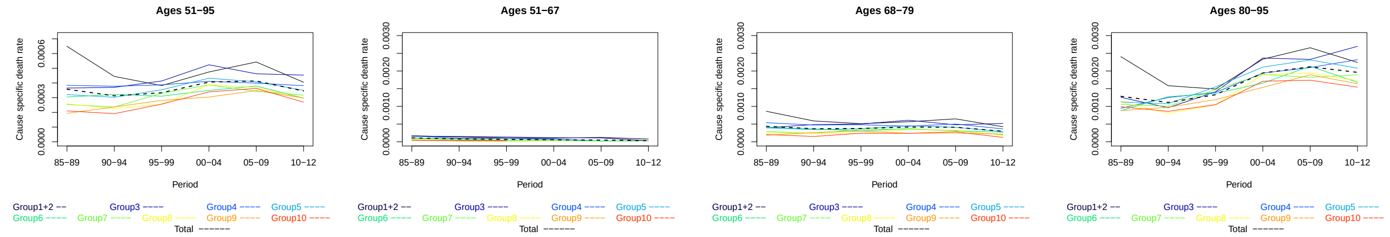


(e) Infection diseases and tuberculosis

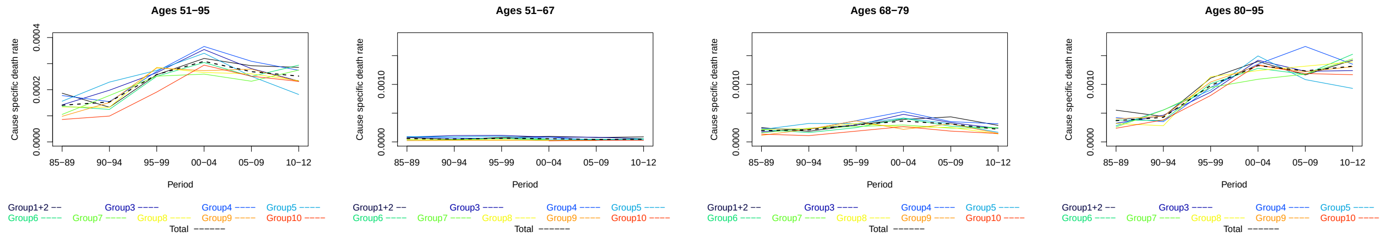


(f) Digestive diseases

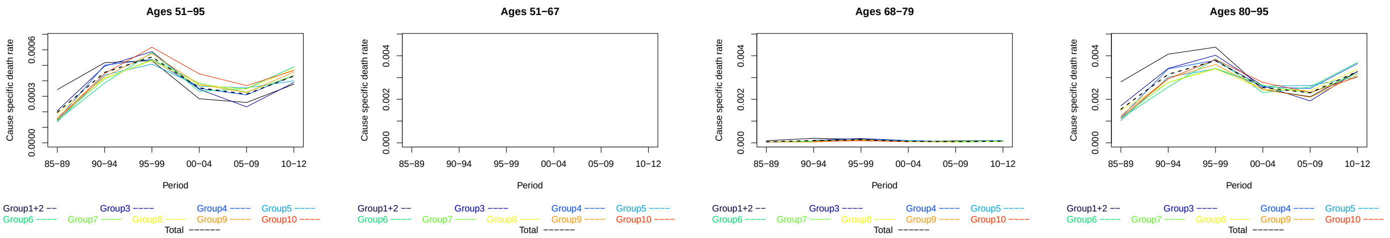
Figure 11: Cause of death rates for Danish women in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



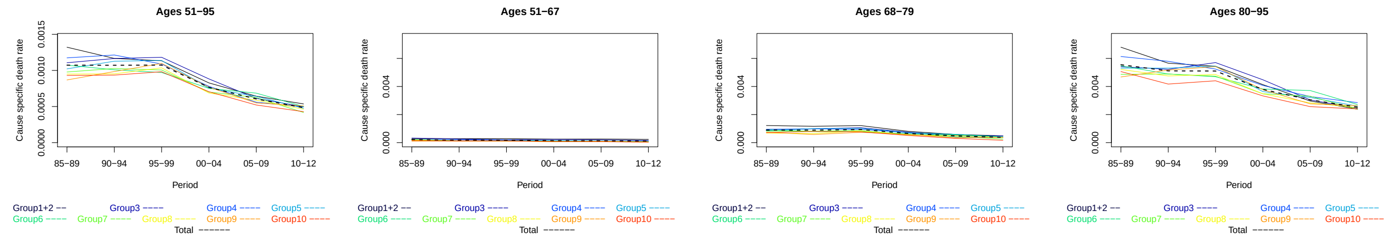
(a) Diseases urine, kidney, genital organs and breast gland



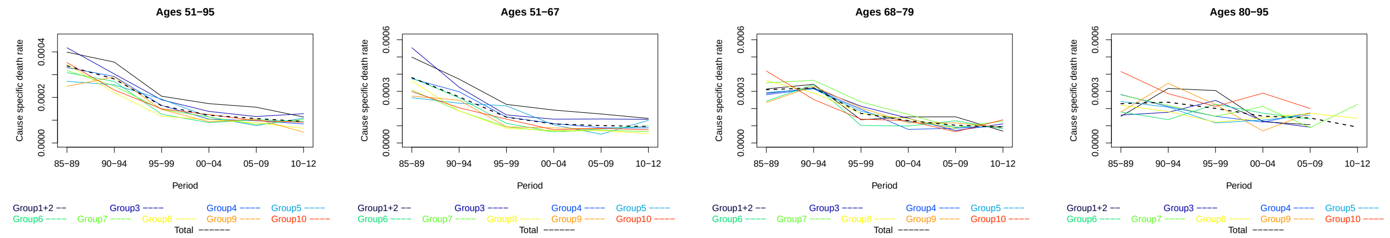
(b) Diseases in skin, bones and connective tissue.



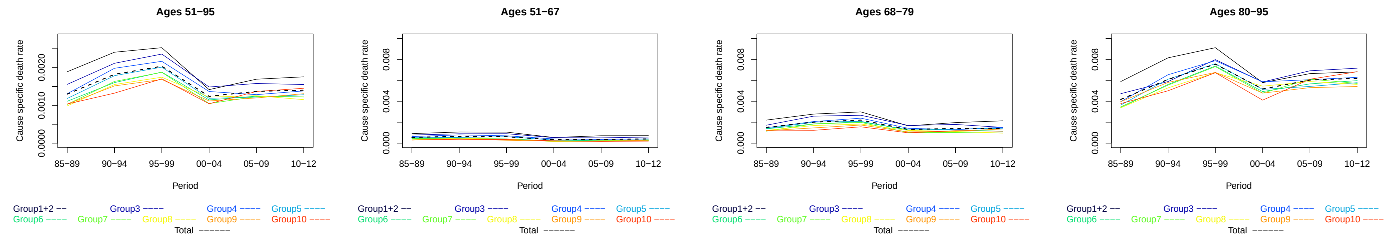
(c) Senility without mental illness.



(d) Road and other accidents



(e) Suicide.



(f) Other causes of death.

Figure 12: Cause of death rates for Danish women in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12

system combined accounts for more than 40 percent of all deaths and thus have a significant impact on the observed pattern in Figure 7. The only disease related to the circulatory system that display increases in death rates over time is other heart diseases (Figure 10c). However, it occurs at a similar pace for all affluence groups and the gap is decreasing over time.

Interestingly cancer in uterus and cervix had a clear socio-economic gradient in the early periods with much higher death rates for the low-middle and middle affluence groups which disappeared over the time period. This is likely a consequence of the introduction of the cervical cancer screening program in 1962 (only one municipality) which was fully implemented in all municipalities in 2006. It has clearly decreased the overall cause specific death rate and eroded the socio-economic differences. The decreasing socio-economic gradient is also observed for road and other accidents (Figure 12d), suicide (Figure 12e) and other causes of deaths (Figure 12f).

It is seen that cancer in gut or rectum (Figure 8b) and cancer in lymphatic or blood-forming tissues (Figure 9b) does not show any clear socio-economic gradient. Mental illnesses (Figure 11c) and meningitis and diseases in the nervous system as well as sense organs (Figure 11d) also show no district social gradient except the massive difference in death rates between group 1+2 and all other groups in the 80s and 90s. Finally senility without mental illness (Figure 12c) and breast cancer (Figure 8d) also displays a limited social gradient. In fact we see a reverse social gradient in later time periods.

Some causes of deaths display a consistent social gradient over time such as cancer in mouth, gullet and stomach (Figure 8a), cancer in bones, skin or other unspecified locations (Figure 9a), benign tumours or tumours without specification (Figure 9c), increased blood pressure or rheumatic fever (Figure 10a), diseases in blood and blood forming organs, as well as endocrine sufferings and deficiency diseases (Figure 11a), digestive diseases (Figure 11f), diseases urine, kidney, genital organs and breast gland (Figure 12a), and diseases in skin, bones and connective tissue (Figure 12b) .

In conclusion, we find that causes of death related to smoking are contributing to the slowdown in female longevity for the low-middle and middle affluence groups in the 80s and 90s as these groups display higher increases in death rates for smoking related causes of deaths, but are not able to single-handedly explain the slowdown. However the lack of improvements in deaths relating to the circulatory system and in particular ischemic heart diseases are important in explaining the slowdown as well as the following catch up effect in life expectancies. In 1985, 25% of all deaths were causes by ischemic heart diseases whereas in 2012 this number was reduced to around 10% and almost completely eliminating the socio-economic gap. Thus the political decision to add significant funding to this area has proven highly beneficial in terms of gains in life expectancy for women and men. Another cause of death where adherence to a specific affluence group no longer has an impact is cancer in uterus and cervix. The low-middle and middle affluence groups had much higher death rates compared to the other affluence groups in the 80s and 90s. The nationwide introduction of screening programs reduced the death rates for all groups but in particular for the low-middle and middle groups.

5 Forecasting

Naturally it is of utmost importance to have precise prediction of future mortality and life expectancy from an economic as well as public policy perspective. Having subgroup populations obviously improves the information available by removing heterogeneity with the finer disaggregation. However, this leaves the important question on how to use this improved information, with respect to both modelling and prediction. We now investigate this by comparing the performance of single versus multi-population models. Here we compare the benchmark single-population Lee-Carter model with its multi-population generalisation the Li-Lee model. Naturally using specific cause of death rates could provide insightful information about future mortality by extrapolating the cause specific trends. However, due to few deaths within each age, year and group we found it necessary to aggregate substantially across ages and years, leaving 6 time periods and 3 age groups making cause of death forecast unreliable. Thus, we will use all cause age specific death rate in what follows.

Therefore, we now evaluate the out-of-sample forecasting performance based on estimating the models for Norwegian and Danish data from 1985 up until 2000 or 2004 respectively. Hence, producing 8 years of forecasts for both countries. The forecast performance is compared in terms of the mean squared forecast error (MSFE) of the life expectancy as it is intuitively appealing and aggregates all age-specific death rates into a single measure. Herein we compare whether the LL model improve predictions of subgroup life expectancy by exploiting the common (sex-specific) population trend compared to the LC model on each subgroup. Moreover, for illustration we compare the 'pseudo' forecast from only using the total population data with the group specific forecasts to highlight the importance of having detailed group specific knowledge. The results are reported in Table 3 for Denmark and Norway for men and women.

Table 3: The forecast performance for the LC model over the years 2005-2012 for Denmark calculated as the Mean Squared Forecast Error of the life expectancy. The forecasts are produced by using group specific information as well as the full population data.

	Denmark						Norway					
	Women			Men			Women			Men		
	Grp Specific		Total	Grp Specific		Total	Grp Specific		Total	Grp Specific		Total
Grp	LC	LL	LC	LC	LL	LC	LC	LL	LC	LC	LL	LC
1				0.139	0.116	20.010	0.841	0.152	6.757	0.478	0.986	3.665
2	0.120	0.428	7.945	0.432	0.268	10.877	0.359	0.269	3.137	0.117	0.401	1.389
3	2.940	0.159	3.349	0.282	0.418	4.951	0.903	0.386	0.808	0.067	0.319	0.439
4	0.599	0.280	0.486	0.068	0.106	0.735	0.135	0.168	0.082	0.071	0.048	0.246
5	0.229	0.182	0.186	0.207	0.089	0.326	0.292	0.259	0.134	0.147	0.115	0.153
6	0.390	0.242	1.231	0.115	0.266	1.965	0.220	0.107	0.319	0.181	0.154	0.130
7	0.398	0.282	2.627	0.187	0.583	4.119	0.107	0.187	0.912	0.844	0.066	0.273
8	0.276	0.208	3.628	0.483	0.617	7.002	0.433	0.111	1.140	1.003	0.034	0.748
9	0.650	0.438	6.565	0.255	0.849	11.827	0.122	0.142	1.876	0.879	0.423	3.376
10	0.539	0.270	9.517	0.394	1.617	18.047	0.779	0.061	3.868	0.486	0.988	10.596
Tot	0.147		0.147	0.122		0.122	0.150		0.150	0.183		0.183

Comparing the group-specific versus population-specific MSFE's, we clearly see the importance of having detailed information for the subgroups as it considerably reduces the forecast errors, e.g. comparing column 1 and 2 with column 3 for Danish women. This result is consistent across both genders and countries, with the largest gains naturally occurring for the lowest and highest affluence group.

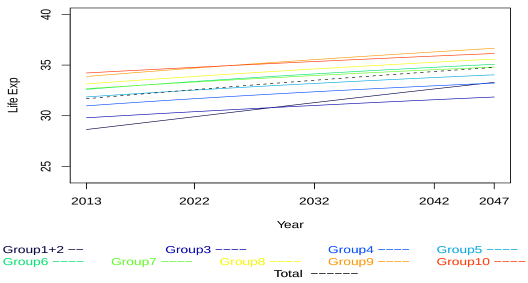
We now compare the performance of the LC and LL model. From Table 3 we see that the LL model gives the lowest MSFE's in 24 out of 39 cases. For Danish and Norwegian women the LL model is the best performing model in 8/9 out of 7/10 cases, whereas for Danish men it is 3/10 cases and 6/10 for Norway. Thus we find the LL model to slightly outperform the LC model on this 8 year out of sample period although the results are not consistent across the genders and countries. We note that the difference from using the LC versus the LL model is typically small compared with having the detailed subgroup data. That neither the LL model or the LC model outperform the other might be due to the short out-of-sample period used. Hence, we will also create predictions and investigate whether they are reliable in what follows.

5.1 Prediction of Subgroup Life Expectancy

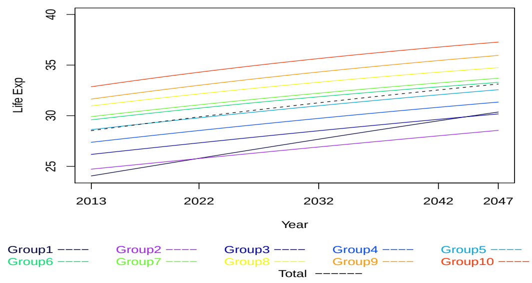
We now show the long term forecasts by predicting the life expectancy 35 years ahead for each subgroup at age 51 for the LC and LL model and show the results for both genders and countries in Figures 13 and 14.

For the LC model we observe cross-overs in the predicted life expectancy between subgroups for both genders and countries. In particular, we see that the least affluence groups for males are predicted to improve significantly and thus approach the level of life expectancy of the middle affluence groups except for all but Norwegian women. Moreover, we find that the most affluent group cross with lower affluence groups for women in both countries. This is a natural implication of extending the in-sample patterns where some groups have experienced larger improvements over the period as described earlier. These cross-overs in terms of predicted life expectancy and mortality is problematic as we have no economic, political, or intuitive explanation as to why the lowest socio-economic groups suddenly should start living longer compared to more affluence groups. We might expect catch-up effects or convergence in life expectancy over time between different affluence groups, but cross-overs are intuitively implausible.

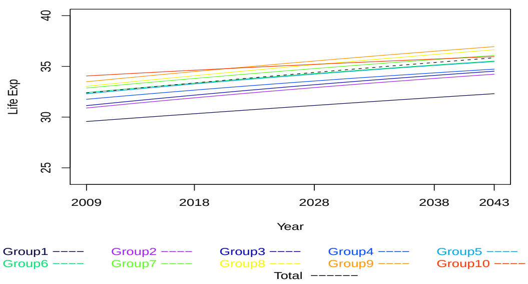
This issue is however not observed for the LL model as it account for the general population trend in the group-specific forecasts. Here a clear ranking across subgroups are observed over time for both genders and countries. We note however that a small convergence between the subgroups over time are implied by construction of the model, due modelling the overall trend in logs. Further, to investigate the forecast uncertainty we produced prediction intervals where adjacent groups were found to have overlapping intervals as would intuitively be expected. However, we omit to show these plots due to space constraints and messy graphs.



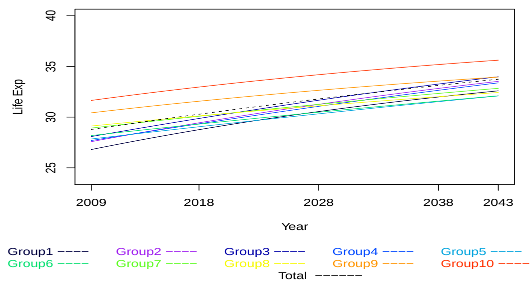
(a) Predictions for Danish women, LC model



(b) Predictions for Danish men, LC model

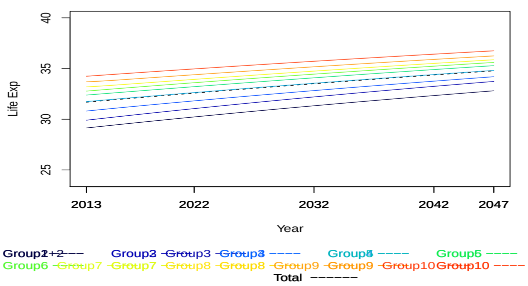


(c) Predictions for Norwegian women, LC model

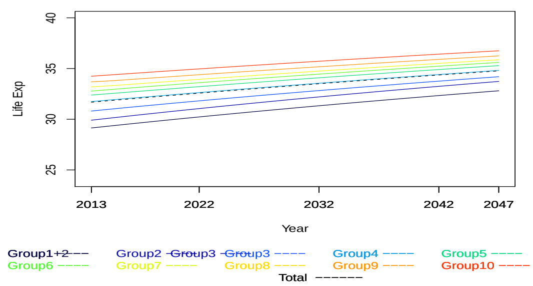


(d) Predictions for Norwegian men, LC model

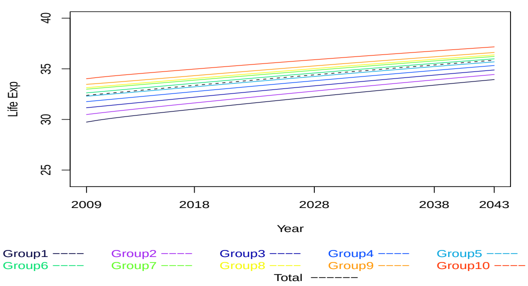
Figure 13: 35 year ahead predictions of life expectancy using the LC model for Danish and Norwegian men and women.



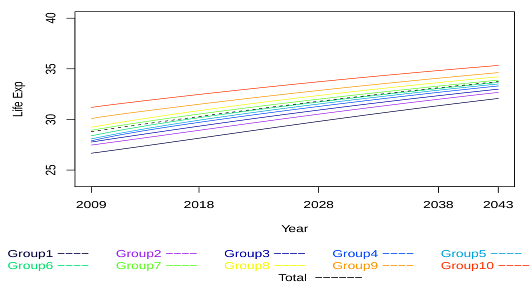
(a) Danish women



(b) Danish men



(c) Norwegian women



(d) Norwegian men

Figure 14: 35 year ahead predictions of life expectancy using the LL model for Danish and Norwegian men and women.

6 Conclusion

In Scandinavia a decrease in mortality rates have been observed for Norwegian and Swedish females, in contrast to a stable or in some cases even increasing mortality rate for Danish females in the time period 1980-1995. The standstill in this period is not unique to Denmark as it was also observed for the US and Netherlands, see Meslé and Vallin (2006). Understanding this puzzle as well as which socio-economic groups and causes of death drive the differences in longevity is essential for governments, pension funds and insurance providers.

Governments are faced with tasks of implementing policy measures that will reduce social inequality and improve life expectancy for all groups in society. This requires different policy measures due to dissimilar trends in health and mortality across the socio-economic groups. Moreover governments need to carefully manage their health care costs which are found to be much higher for the lower affluence groups due to a reverse social gradient in health care costs observed in the Scandinavian countries. The health cost for the poorest fifth is twice that of the richest, see Christensen et al. (2016). For pension funds and life insurers it's critical to manage the mortality experience and developments of their members. Having detailed subgroup specific information can help in identifying and managing this risk.

Using unique and extensive individual specific register data for Denmark and Norway we partition the populations into 10 socio-economic groups based on the new affluence measure developed for males in Cairns et al. (2016) using income and wealth. We find the affluence index to work well as a proxy for life expectancy by tracking substantial differences in life expectancy across the socio-economic groups.

We find a clear ranking of life expectancy across the affluence groups from the lowest to the highest for both genders and countries. In particular we obtain differences in life expectancy of up to 7-8 years for 51 year old males and 5-6 years for 51 year old females in the mid-1980s, confirming earlier findings of a larger socio-economic gap for men than women.

We find that the decline in life expectancy for Danish women is present for all subgroups, however with particular large decreases for the low-middle and middle affluence. In contrast, all subgroups for Danish men as well as Norwegian men and women exhibit positive improvements over the period. Interestingly, we see that the lowest affluence groups for Danish women actually see large improvements in life expectancy for the oldest ages, i.e. 80-95 year olds. We find that the causes of deaths related to smoking are partly contributing to the slowdown in female longevity as the low-middle and middle affluence groups display higher increases in death rates for smoking related causes of deaths. However the lack of improvements in deaths relating to ischemic heart diseases is dominant in explaining the slowdown as well as the following catch up effect in life expectancies.

We estimated the well-known Lee-Carter and Li-Lee models and investigated their in-sample fit and forecast performance across the socio-economic groups. Overall, we found that the model fit only decreased slightly by having smaller populations. Moreover, we found that using the common factor from the overall population in the Li and Lee model improved the forecasting performance compared with the Lee-Carter model. This was especially important when investigating longer forecast horizons as it avoided unrealistic crossovers.

7 Disclosure Statement

No potential conflict of interest was reported by the authors.

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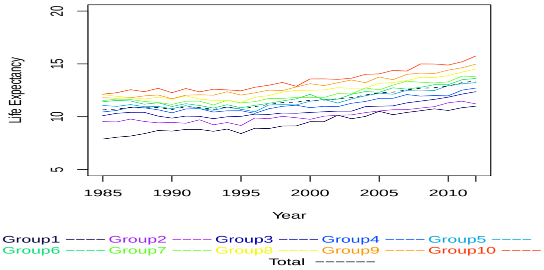
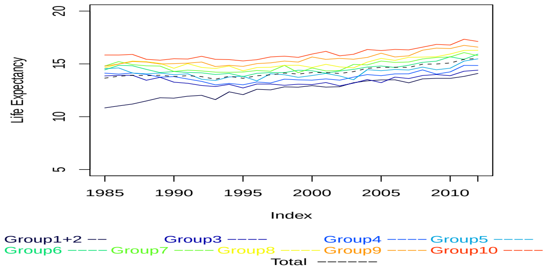
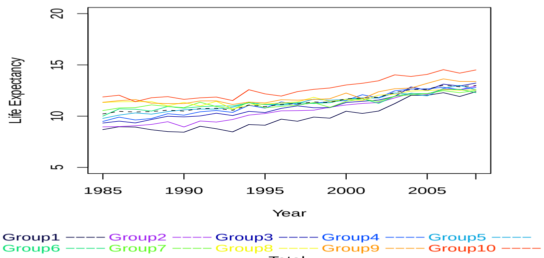
A Life Expectancy at Old Ages



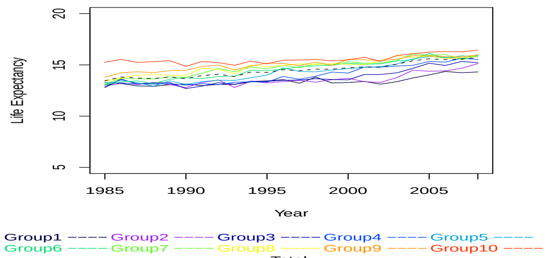
(a) Danish men



(b) Danish women

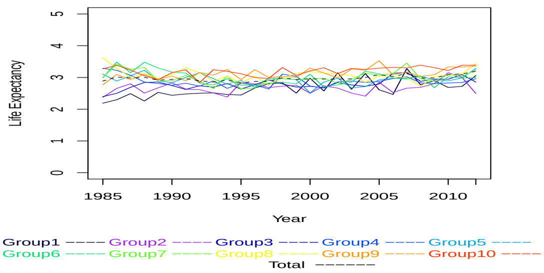


(c) Norwegian men

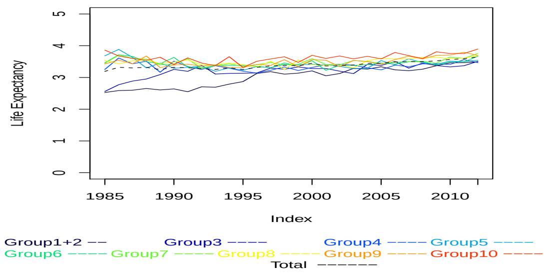


(d) Norwegian women

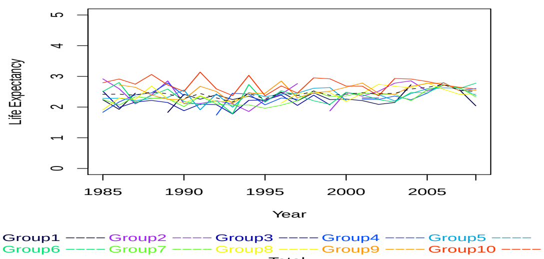
Figure 15: The life expectancy for the affluence groups 1-10 at age 70, for Danish and Norwegian men and women for the period 1985-2008/2012



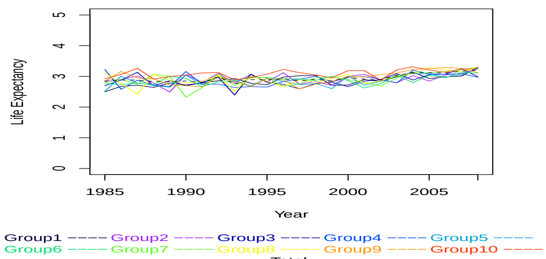
(a) Danish men



(b) Danish women



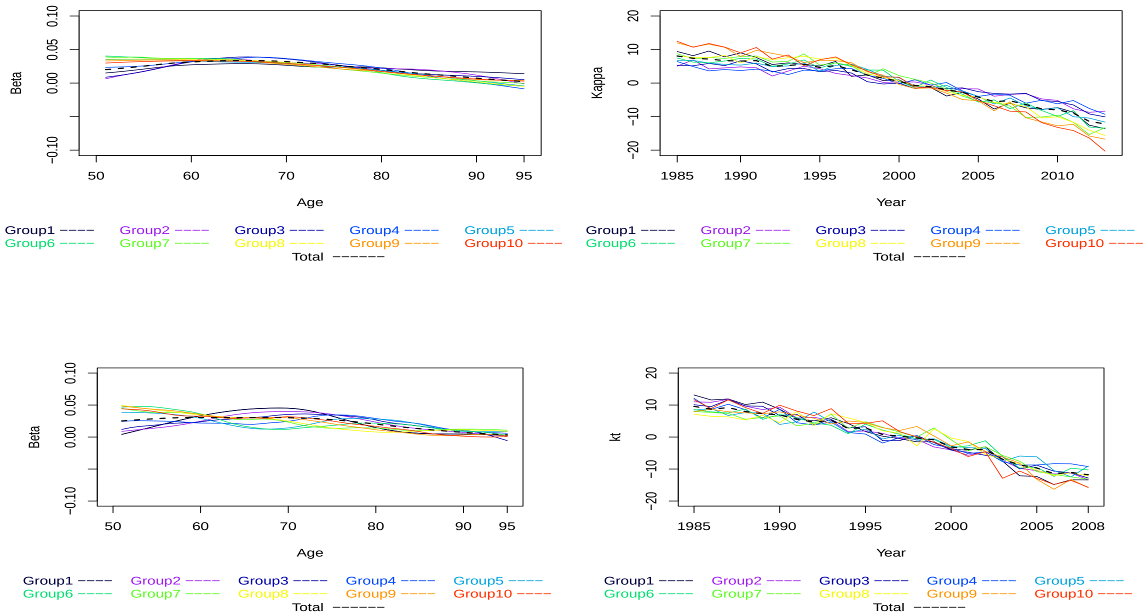
(c) Norwegian men



(d) Norwegian women

Figure 16: The life expectancy for the affluence groups 1-10 at age 90, for Danish and Norwegian men and women for the period 1985-2008/2012

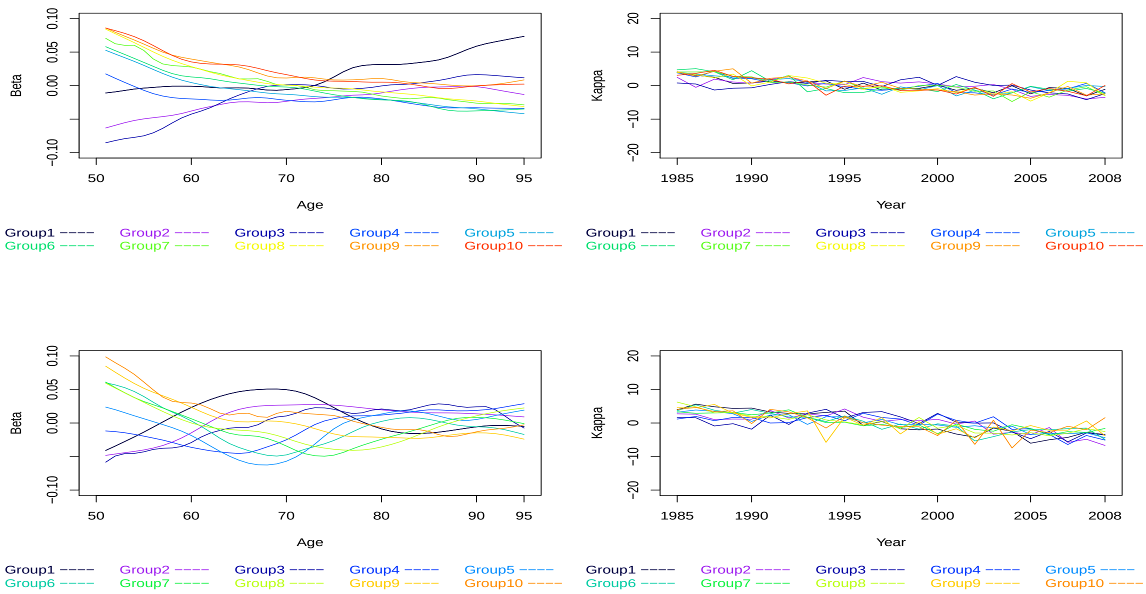
B Paremeter Estimates for Men



(c) LC β_x Norwegian men

(d) LC κ_t Norwegian men

Figure 17: The β_x and κ_t estimates for men in Denmark and Norway using the LC model, for each of the ten affluence groups.

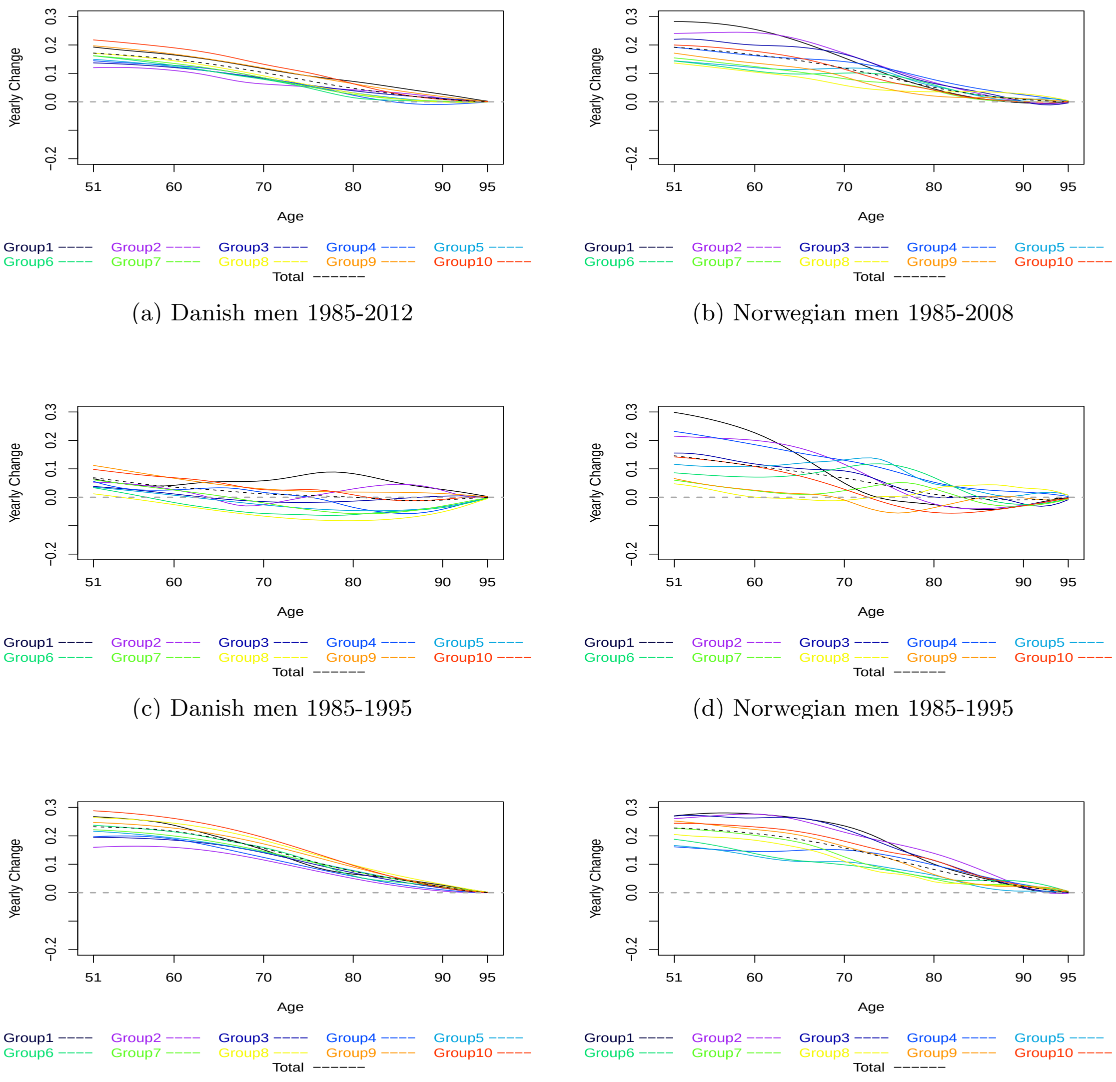


(g) LL β_x Norwegian men

(h) LL κ_t Norwegian men

Figure 18: The β_x and κ_t estimates for men in Denmark and Norway, for each of the ten affluence groups in the Li-Lee model.

C Average Yearly Changes in Life Expectancy for Men



(a) Danish men 1985-2012

(b) Norwegian men 1985-2008

(c) Danish men 1985-1995

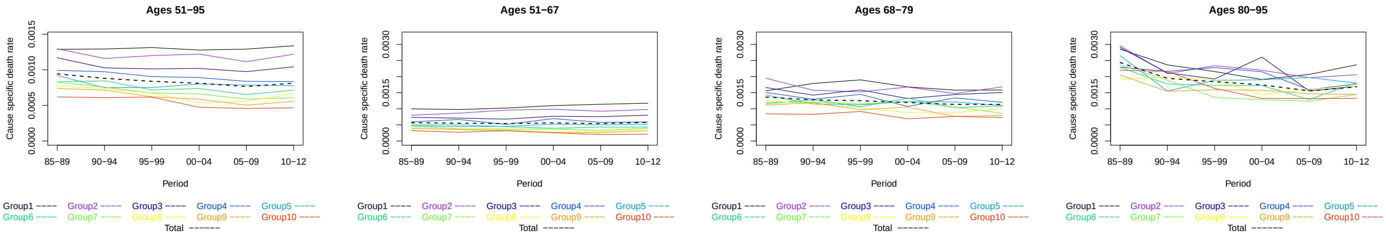
(d) Norwegian men 1985-1995

(e) Danish men 1995-2008

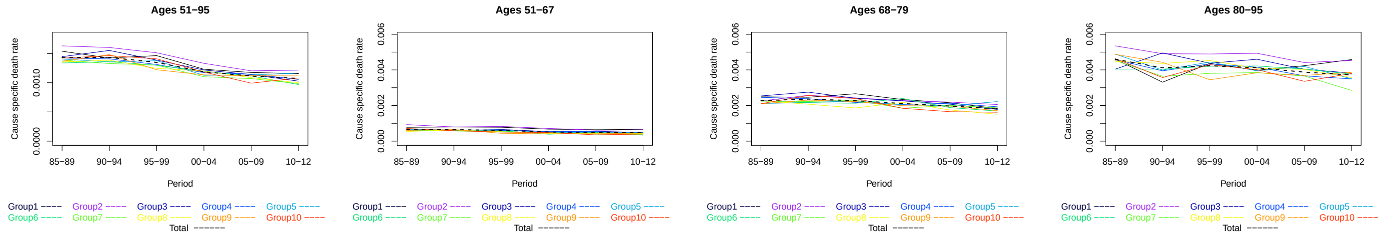
(f) Norwegian men 1995-2008

Figure 19: The average yearly changes in life expectancy for Norwegian and Danish men for the full period as well as 1985-1995 and 1995-2008/12.

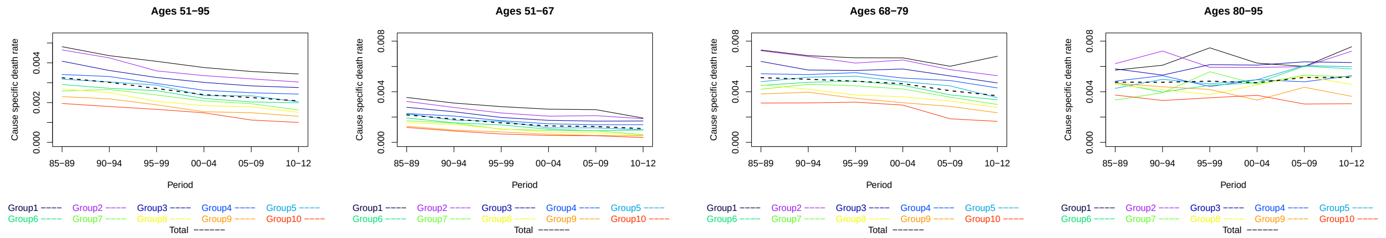
D Cause Specific Death Rates for Danish Men



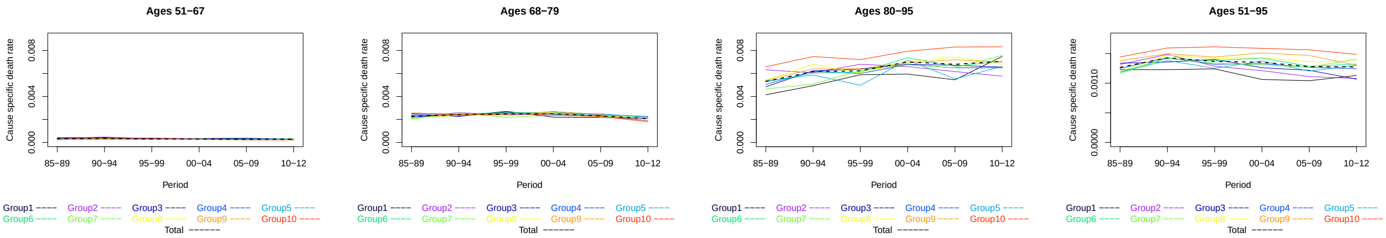
(a) Cancer in mouth, gullet and stomach



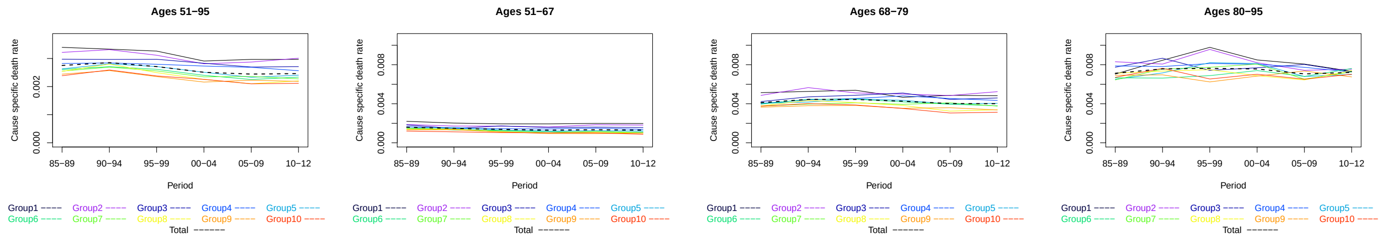
(b) Cancer in gut or rectum



(c) Cancer in larynx, trachea, bronchus or lungs

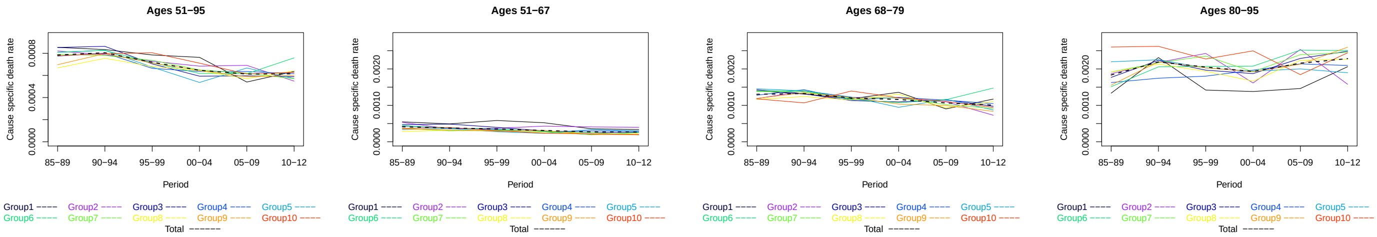


(d) Testicle cancer.

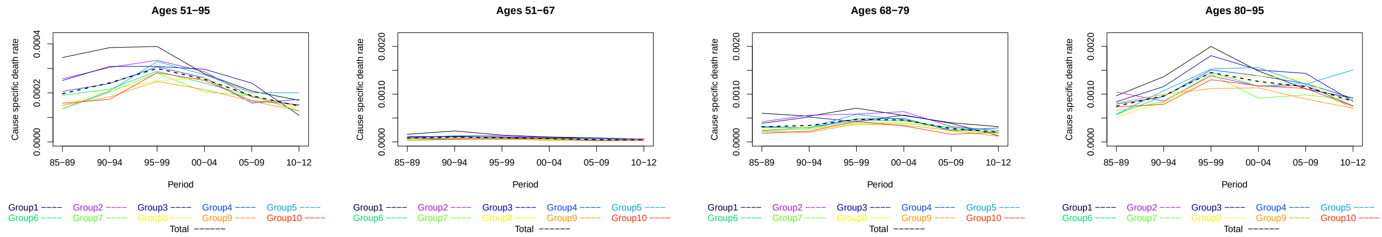


(e) Cancer in bones, skin or other unspecified locations.

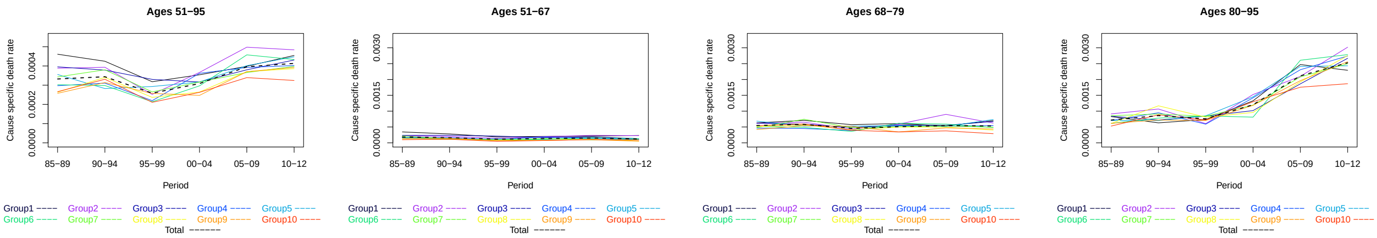
Figure 20: Cause of death rates for Danish men in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



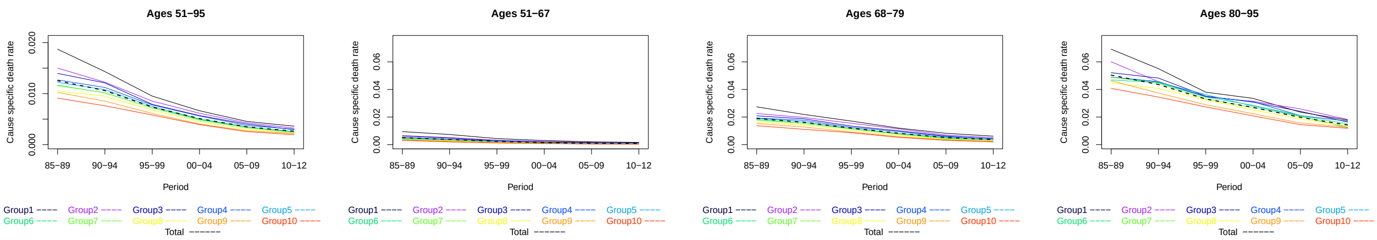
(a) Cancer in lymphatic or blood-forming tissues



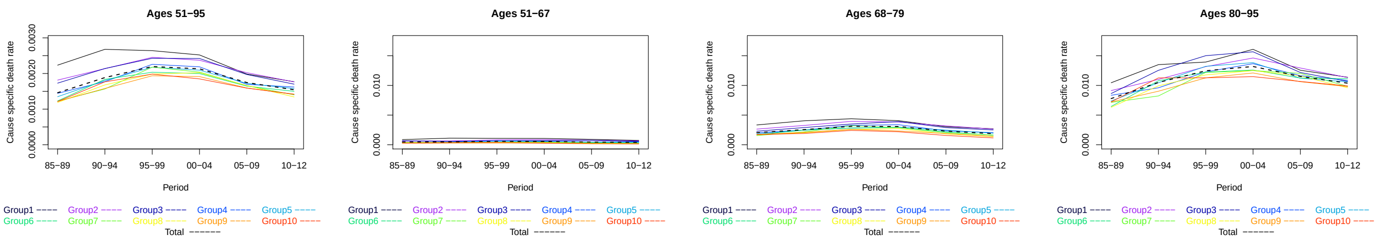
(b) Benign tumours or tumours without specification.



(c) Increased blood pressure or rheumatic fever

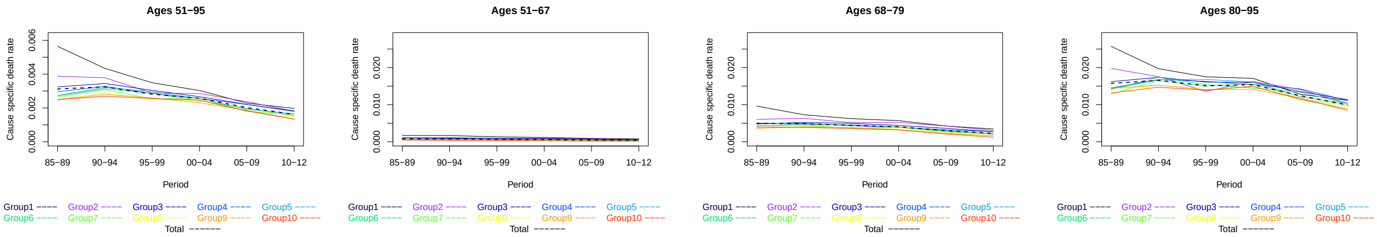


(d) Ischaemic heart diseases

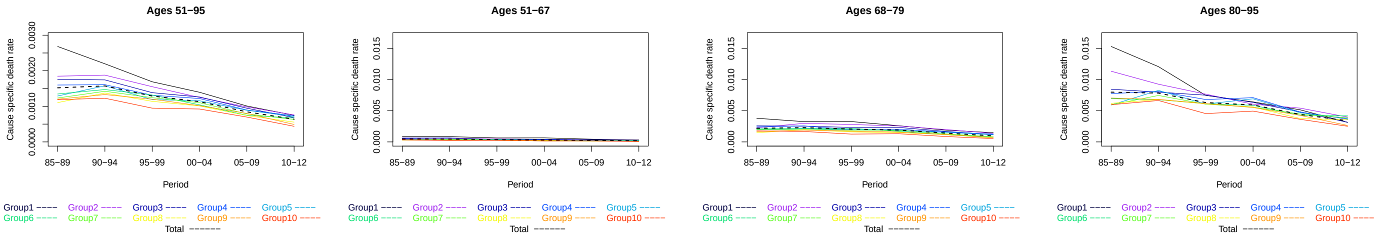


(e) Other heart diseases

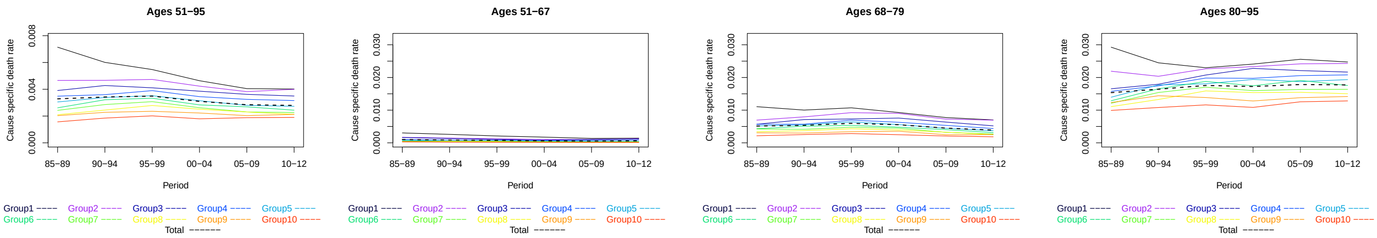
Figure 21: Cause of death rates for Danish men in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



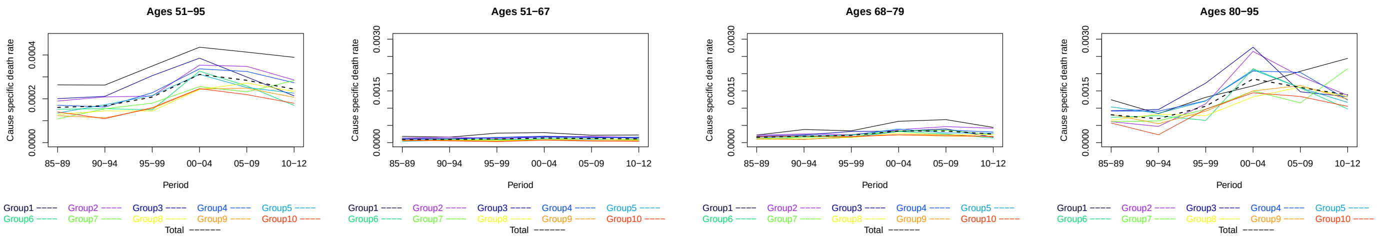
(a) Cerebrovascular disease



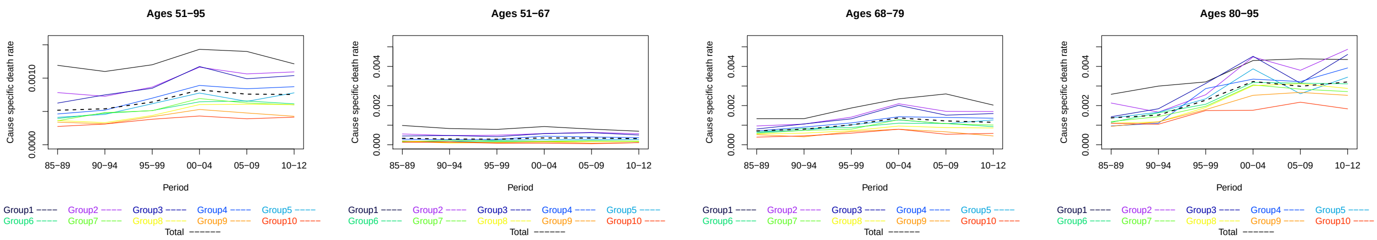
(b) Circulatory diseases



(c) Lungs and breathing diseases

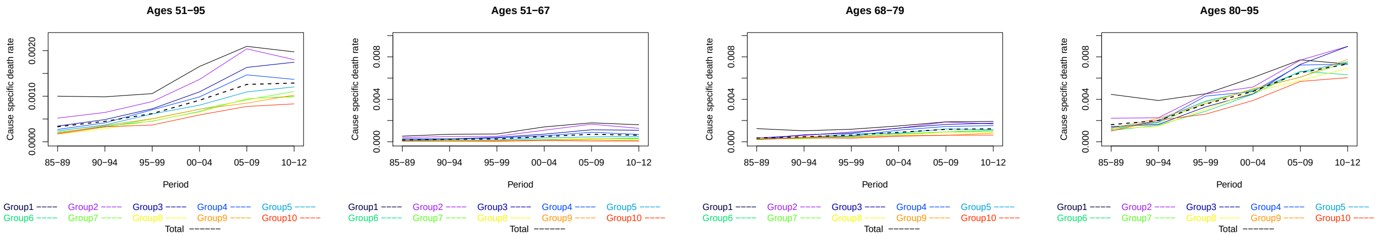


(d) Diseases in blood and blood forming organs, as well as endocrine sufferings and deficiency diseases.

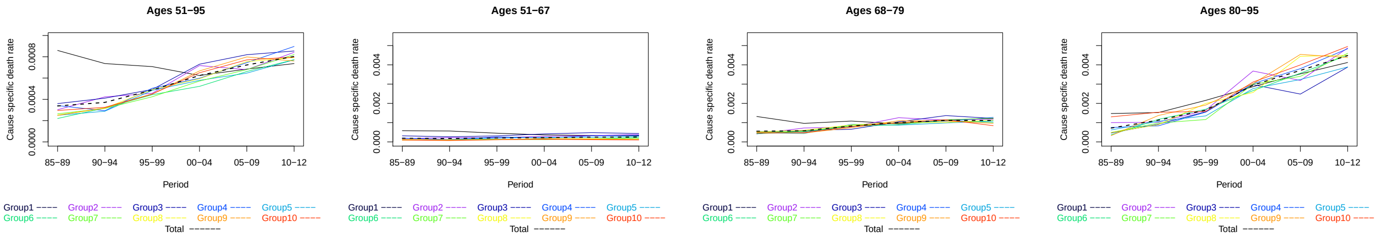


(e) Diabetes

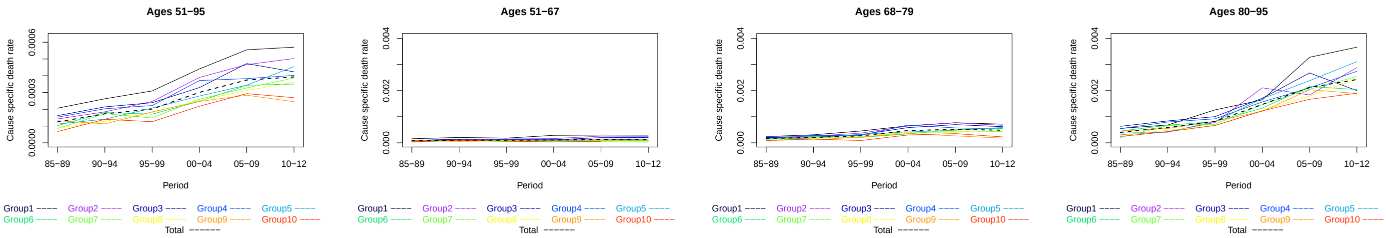
Figure 22: Cause of death rates for Danish men in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



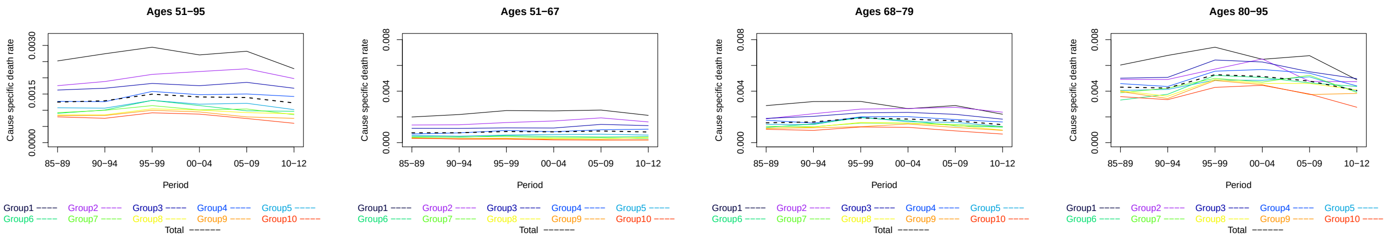
(a) Mental illnesses



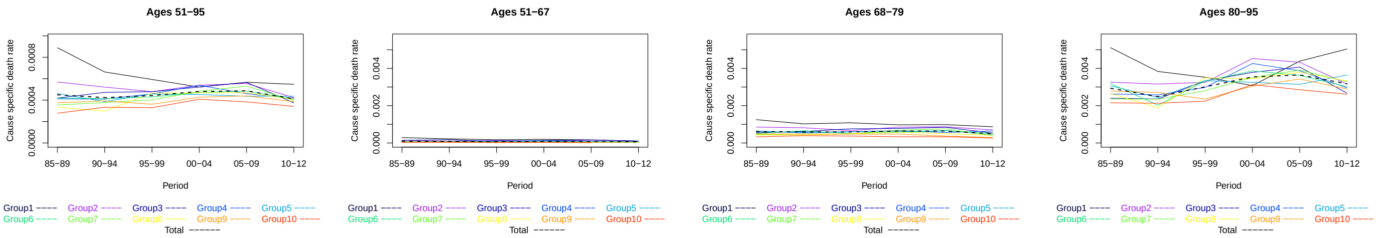
(b) Meningitis and diseases in the nervous system as well as sense organs.



(c) Infection diseases and tuberculosis

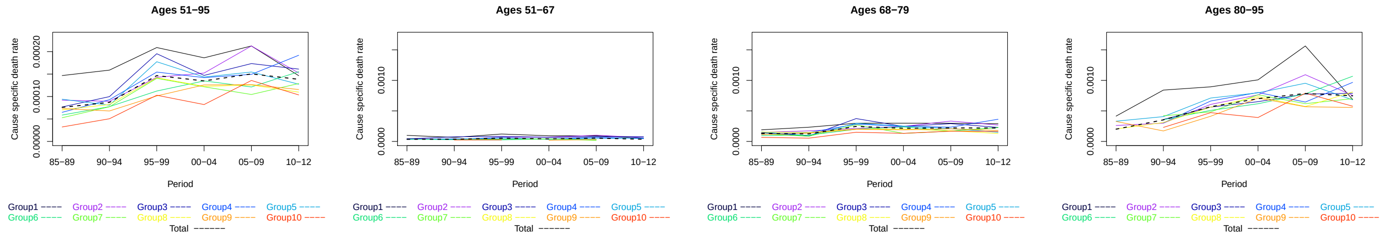


(d) Digestive diseases

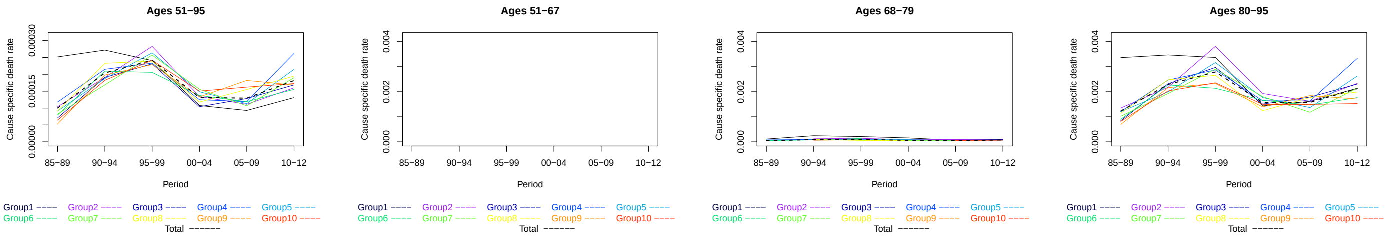


(e) Diseases urine, kidney, genital organs and breast gland

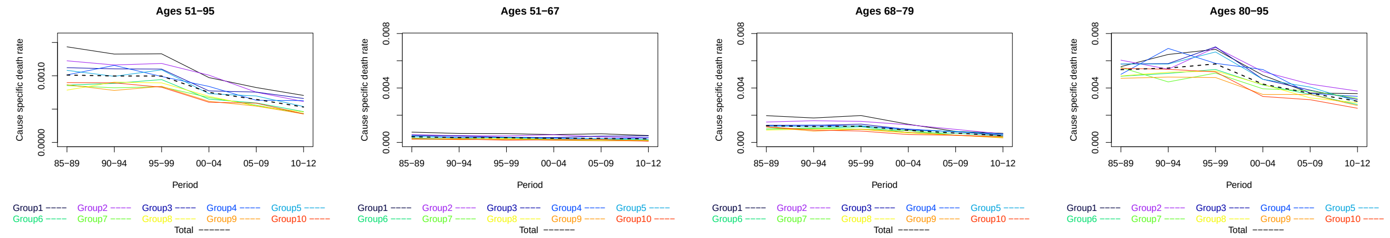
Figure 23: Cause of death rates for Danish men in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12



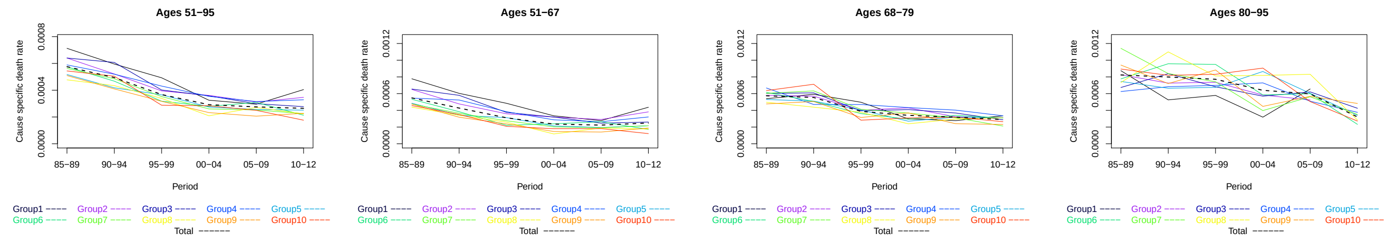
(a) Diseases in skin, bones and connective tissue.



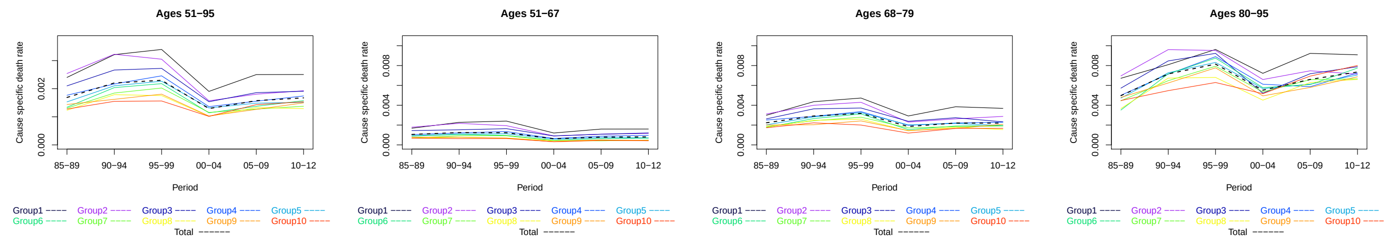
(b) Senility without mental illness.



(c) Road and other accidents



(d) Suicide.



(e) Other causes of death.

Figure 24: Cause of death rates for Danish men in the years 1985-89, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-12

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