Cohort Survival Comparisons among Industrialized Countries: The Truncated Cross-sectional Average Length of Life Approach.

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Abstract

Background: The longevity progress in developed countries has not been observed uniformly, triggering a mortality gap between them. In addition to knowing that the mortality disparity exists, a deeper understanding is obtained by recognizing at which ages survival differences specifically appear.

Objective: To investigate how different cohorts present in 2010 contribute to the longevity gap between countries.

Methods: 34 countries from the Human Mortality Database were selected. Each country was compared against the created group of other high-longevity countries (HLC). We calculate the *Truncated Cross-sectional Average Length of Life* (*TCAL*) in 2010 for all countries, and decomposed the differences between countries' *TCALs* by age and cohort.

Results: Nordic and Western-central Europe, as well as the selected Non-European countries, experienced a cohort survival advantage compared with other HLCs in 2010, while Southern and Eastern-Europe experienced lower cohort survival than other HLCs. The age-cohort decomposition of differences in *TCALs* revealed recent cohort developments: higher infant/child mortality in Non-European countries compared with other HLCs, and lower infant/child mortality in Southern-Europe than in other HLCs. Only the oldest Nordic cohorts born before 1920 reduced the overall survival advantage of Northern-Europe compared with other HLCs in 2010. A similar cohort survival trajectory was experienced by Western-central European cohorts compared with other HLCs. All the Eastern cohorts present in 2010 experienced higher mortality than other HLCs.

Contribution: We complement research of mortality gaps by adding now a cohort survival perspective. While gaps in life expectancy at birth reflect disparities in current mortality, differences in *TCALs* add the historical mortality information.

Keywords: mortality gap; age-cohort decomposition; cohort mortality; longevity

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1. Introduction

Since the mid-nineteenth century, the developed world has experienced great progress in survival (Oeppen and Vaupel 2002; Vallin and Meslé 2004). Improvements in sanitation, hygiene, nutrition, housing, and medical technology all contributed to the mortality decline (McKeown et al. 1972; Fogel 1997; Cutler et al. 2006). However, these improvements have not affected all countries uniformly, creating a mortality gap between them (Tuljapurkar et al. 2000; Ho and Preston 2010; Murray and Frenk 2010; Canudas-Romo and Engelman 2012; United Nations 2013; National Academies of Sciences 2015).

Throughout history, investments in reducing mortality have been focused in age groups with high mortality levels. During the 18th century and beginning of 19th, the highest mortality rates were concentrated in the first years of life (Omran 1971; Hill 1990). In this period, the greatest improvement in survival was attributed to mortality decline at young ages (Bengtsson and Ohlsson 1994). Northern and Western-Europe were the leading regions in infant/child mortality reductions. From the last third of 19th century to World War I, discoveries of Pasteur and Koch, and improvements in sanitation helped reducing mortality by diarrhea, tuberculosis and cholera (Kirk 2006; Mckeown et al. 1975), and child mortality started to decline in other parts of Europe as well. After World War II, the spreading use of antibiotics accelerated the mortality decline at first ages in Southern and Eastern-Europe (Kirk 2006).

In the twentieth century, in places where mortality at first ages had already achieved low levels, new challenges emerged to improve longevity. A transition is then observed from a period dominated by infant/child mortality reductions to a period dominated by reductions in mortality among adults and elderly (Bergeron-Boucher et al. 2015; Canudas-Romo 2010; Vallin and Meslé 2004). After the 1960s, these countries experienced increasing rates of mortality improvements at old ages (Kannisto et al. 1994). However, in Eastern-Europe, which suffered high death rates among adults, declines in mortality at advanced ages were lower than in more developed parts of Europe (Meslé 2004).

International comparisons of mortality are not new (National Research Council 2011; United Nations 2013; Whelpton 1947). Rankings of life expectancy reveal the highest expectation of life and provide information about the performance of countries respect to others (Guillot and Canudas-Romo 2016; Murray and Frenk 2010; National Research Council 2010; Oeppen and Vaupel 2002). However, in addition to knowing that the mortality gaps exist, it is relevant to recognize at which ages survival differences specifically appear. To achieve this, decomposition methods to investigate differences between life expectancies by age, sex, and causes of death have been developed and widely used (Andreev et al. 2003; Arriaga 1984; Beltran-Sanchez et al. 2008; Horiuchi et al. 2008; Pollard 1988; Vaupel and Canudas-Romo 2003). These methods usually compare two populations at a given time, or one population in two different points in time. This holds for both, period and cohort perspectives. However, to capture the mortality dynamics of populations, it is important to include all the cohorts present in a given moment in order to investigate how cohorts progressed to the current levels. To address this perspective, here we focus on how the cohort's advantage (disadvantage) of lower (higher) mortality levels by age accumulated over the years to the mortality currently observed among industrialized countries. To do that, we decompose the *Truncated Cross-sectional Average Length of Life* (*TCAL*) by age and cohort (Canudas-Romo and Guillot 2015).

TCAL is a period age-aggregated measure that summarizes historical mortality information about all cohorts present at a given time and it is not limited to populations with complete cohort mortality data. Thus, populations such as the Japanese with full mortality data only starting in 1949, can also be included in the analysis (Canudas-Romo and Guillot 2015). Motivated by the information that the cohort analysis can add, we aim to compare in a cohort perspective several industrialized countries.

To investigate how different cohorts of industrialized countries present in 2010 contribute to the mortality gap respect to a group of high-longevity countries (HLCs), we decomposed mortality differences by age and cohort. This decomposition suggested the pace how cohorts get depopulated over life, and revealed the short- or long-lasting effect of mortality decline. We selected 34 industrialized countries and compare them with other HLCs. These countries were clustered into five groups. Then, we assess within group comparisons, and between groups gaps in *TCALs*.

2. Methods

To calculate $TCAL(t,Y_1)$, we should define the year *t* that we are interested to estimate the measure at, and the earliest year for the available mortality series Y_1 (Canudas-Romo and Guillot 2015). Thus, the *TCAL* for year *t*, truncated at year Y_1 is computed as,

$$TCAL(t,Y_1)=\int_0^{\omega}\ell(x,t,Y_1)dx\,, \qquad (1)$$

where $\ell(x,t,Y_1)$ is the survival function for cohorts reaching age *x* in year *t*, which were born in year $t-x$. Some of these cohorts were born after year Y_1 and have full cohort information. For those cohorts born before Y_1, and have only partial cohort mortality data, we assume a set of death rates for years before year Y_1. As our interest is the comparison between populations, death rates equal to zero were used for all examined countries at years before Y_1. Thus, we eliminated any confounding effects of death rates before year Y_1, and only focus our comparisons on the available cohort information used (for more details see Canudas-Romo and Guillot 2015). To compare two populations at time *t*, both *TCALs* must be truncated at the same year Y_1. As *TCAL* depends on years *t* and Y_1, different *TCAL* values can be found for the same population when these years change.

The comparison between each country with other HLCs reveals which population experienced higher mortality levels in historical mortality data. Lower *TCAL* values correspond to countries that experienced higher cohort mortality levels than other HLCs.

The age-cohort contribution, $\Delta\left(a,t-x,i\right)$, to the difference between *TCAL* in population *i* and that of other HLC, $TCAL_{HLC}$, can be estimated as

$$\Delta(a,t-x,i)=\left[\frac{\ell(x,t,Y_1,HLC)+\ell(x,t,Y_1,i)}{2}\right]\ln\left[\frac{{}_1p_a(t-x,HLC)}{{}_1p_a(t-x,i)}\right], \qquad (2)$$

where ${}_1p_a(t-x,i)$ is the probability of surviving from age a to $a+1$ for the cohort born in year $t-x$ in population *i*; and as before $\ell(x,t,Y_1,i)$ is the survival function for the cohort aged *x* at time *t* in population *i*. Finally, the summation over cohorts and ages of the age-cohort contributions, $\Delta(a,t-x,i)$, returns the difference in *TCALs*

$$TCAL_{HLC}(t,Y_1)-TCAL_i(t,Y_1)\approx\sum_{x=0}^{\omega}\sum_{a=0}^{x-1}\Delta(a,t-x,i). \qquad (3)$$

Through this decomposition, we compare mortality between cohorts born at the same year and from different populations.

3. Data

We selected 34 countries from the Human Mortality Database (2016), as presented in Table 1. Data prior to 1900 were not needed, since we calculated *TCAL* for 2010 and took those reaching age 110 in 2010 as the last cohort.

Countries were clustered into five groups, based on their similarities in mortality history and geographic region, and groups and country members are presented in Table 1. Group 1 includes Non-European countries, Group 2 Southern-Europe, Group 3 Northern-Europe, Group 4 Western-central Europe, and Group 5 Eastern-European countries. Through this group constellation, mortality comparisons between each group and other HLCs are made. The group of high-longevity countries (HLC) includes countries with the highest life expectancy at birth in the late-2000s. Thus, HLC contains Group 1, 2 (except Greece), 3 and 4. Greece was excluded due to data quality issues with overestimation of old age mortality even for the 2000s (Agorastakis et al. 2015).

The ideal data for our analysis was the use of cohort death rates for all countries. However, few countries in the HMD have cohort death rates for all cohorts present in 2010. To overcome this limitation we used period death rates, assuming that they were similar to the corresponding cohort death rates. Period age-specific death rates for HLCs and for each group were calculated by adding annual death counts and exposures of each country of its corresponding group. This is equivalent to having average age-specific death rates weighted by population size. To check the sensitivity of our average death rates we also calculated death rates for each created group as the arithmetic average of the countries' death rates, giving equal weights for all countries. The results with both, weighted and not-weighted average were similar, indicating the robustness of our results. Here, we only present results from the weighted average death rates. Results from the non-weighted rates are available from the authors upon request.

4. Results

Table 1 is ranked from highest to lowest in terms of life expectancy at birth (e_0) among groups. At the top of Table 1 is the group of Non-European countries, followed by Southern-Europe, Northern-Europe, fourth is Western-central Europe and finally Eastern-Europe at the bottom of the ranking. A different arrangement of Table 1 is observed if we order regarding *TCAL*: Northern-Europe moves from 3rd position for e_0 to 1st for *TCAL*. Western-central Europe also goes up on ranking from 4th to 3rd, while Non-European countries move from 1st to 2nd for *TCAL*, Southern-Europeans from 2nd for e_0 to 4th for *TCAL*, and finally Eastern-Europe remains for both rankings at the bottom of the Table 1. Nevertheless, the rankings by *TCALs* are not optimal given the differential cohort mortality history available for countries which gives advantage to those with shorter mortality series, as the Eastern-European countries. This advantage originates on the lower death rates experienced in recent years as opposed to higher levels of the past. Still, this exemplifies the great existent differential between current and cohort mortality as depicted by e_0 and *TCAL*. The results for female and male population are shown in the Appendix, on Table 1A and 1B, respectively.

Table 1 - Countries included in the analysis, and their start (Y_1) and end year (Y_n) of mortality series, regional Group, life expectancy at birth ($e^0(Y_n)$), *TCAL* and differences to the high longevity countries' $TCAL_{HLC}$ for total population.

Country/Group - X	Years Y_1*		Years Y_n**	Group	$e^0(Y_n)$	$TCAL_X$	$TCAL_{HLC}$***	$TCAL_{HLC}$ - $TCAL_X$
Japan	1947	-	2010	1	83.00	79.38	77.32	-2.06
Australia	1921	-	2010	1	82.08	77.69	75.45	-2.24
Canada	1921	-	2010	1	81.40	76.48	75.45	-1.02
New Zealand	1948	-	2008	1	80.39	77.11	77.04	-0.08
United States	1933	-	2010	1	80.36	75.41	76.12	0.71
Group 1	**1921**	**-**	**2010**	-	**82.65**	**76.02**	**75.45**	**-0.57**
Italy	1900	-	2010	2	82.10	74.86	75.32	0.46
Spain	1908	-	2010	2	82.04	74.34	75.32	0.99
France	1900	-	2010	2	81.44	75.81	75.32	-0.48
Greece	1981	-	2010	2	80.52	80.01	80.21	0.20
Portugal	1940	-	2010	2	79.97	72.62	76.67	4.05
Group 2	**1900**	**-**	**2010**	-	**81.43**	**74.66**	**75.32**	**0.66**
Iceland	1900	-	2010	3	81.83	77.75	75.32	-2.43
Sweden	1900	-	2010	3	81.52	77.94	75.32	-2.61
Norway	1900	-	2010	3	81.03	77.28	75.32	-1.95
Finland	1900	-	2010	3	80.01	74.91	75.32	0.42
Denmark	1900	-	2010	3	79.24	75.07	75.32	0.26
Group 3	**1900**	**-**	**2010**	-	**80.60**	**76.15**	**75.32**	**-0.83**
Switzerland	1900	-	2010	4	82.31	77.93	75.32	-2.61
Netherlands	1900	-	2010	4	80.82	76.81	75.32	-1.49
Luxembourg	1960	-	2010	4	80.61	77.34	78.25	0.91
Austria	1946	-	2010	4	80.50	76.69	77.32	0.63
United Kingdom	1922	-	2010	4	80.41	75.95	75.49	-0.47
Germany	1956	-	2010	4	80.23	77.38	77.99	0.61
Ireland	1950	-	2009	4	79.74	76.41	77.40	0.99
Belgium	1919	-	2010	4	80.06	75.06	75.40	0.34
Group 4	**1900**	**-**	**2010**	-	**80.42**	**75.76**	**75.32**	**-0.44**
Czech Republic	1950	-	2010	5	77.56	74.28	77.66	3.38
Estonia	1959	-	2010	5	75.90	71.59	78.19	6.60
Poland	1958	-	2009	5	75.71	73.10	77.95	4.85
Slovakia	1950	-	2009	5	75.49	72.18	77.40	5.22
Hungary	1950	-	2009	5	74.29	70.75	77.40	6.65
Bulgaria	1948	-	2010	5	73.72	70.93	77.42	6.49
Lithuania	1959	-	2010	5	73.19	71.56	78.19	6.63
Latvia	1959	-	2010	5	72.57	70.31	78.19	7.87
Belarus	1959	-	2010	5	70.45	69.75	78.19	8.43
Ukraine	1959	-	2010	5	70.27	69.04	78.19	9.14
Russia	1959	-	2010	5	68.83	67.32	78.19	10.87
Group 5	**1948**	**-**	**2010**	-	**69.85**	**68.02**	**77.13**	**9.11**
HLCs	**1900**	**-**	**2010**	-	**80.51**	**75.32**	-	-

Source: authors's calculation, based on HMD data. *Notes:* * Y_1=The earliest year of the mortality series.** Y_n= The latest year of the mortality series. ****TCAL* for the other HLCs is calculated based on the earliest and latest year of the mortality series of the country/group-X. The group values are calculated similar to the HLCs based on average death rates for the earliest and latest year of the countries.

To further assess mortality experienced by all groups, we divide the analysis into two sections: 1) A between and within group *TCAL*-comparisons, and 2) A decomposition of *TCAL* differences by age and cohort.

4.1. Between and within group cohort survival comparison

Table 1 shows the *TCAL* differences between each group and other HLCs in 2010. Northern-Europe experienced the highest cohort survival advantage compared with other HLCs, about 4/5 of a year, followed by Non-European countries (0.57) and Western-central Europe (0.44). The Southern and Eastern-European *TCAL* is lagging behind the other HLCs, by 0.66 and 9.11 years, respectively.

Table 1 also presents the range of *TCAL* differences within each group, revealing the cohort survival diversity within group. The range between Non-European countries and other HLCs was about 3 years. All countries of this group, except the US, experienced a cohort survival advantage compared with other HLCs in 2010. The American *TCAL* was ¾ of a year lower than that of other HLCs. Another way of comparing mortality between these countries is to examine the life expectancy gap (Table 1). The American e_0 was 0.15 year lower than that of HLCs in 2010. In both comparisons mortality is higher in the US than in other HLCs. However, differences in current mortality between the US and other HLCs are considerably lower than differences in cohort mortality history.

The group of Southern-Europe presented a wide range of *TCAL* differences, about 5 years. France was the only country which experienced higher *TCAL* than other HLCs in 2010. Analysis of the life expectancy gap tells a completely different story. All countries, except Portugal, had higher e_0 than other HLCs in 2010. This aspect suggests recent mortality improvements in Southern-Europe compared with other HLCs.

The range of *TCAL* differences between Nordic countries and other HLCs was about 3 years. Iceland, Norway and Sweden showed higher cohort survival than other HLCs in 2010. The Danish and Finish *TCAL* lagged behind the values of other HLCs by less than half a year.

The life expectancy gap reveals a similar pattern: only Denmark and Finland lagged behind the other HLCs. Comparisons between the Northern-European group and other HLCs showed a slight difference between the range in life expectancy gap (2.6) and the range of *TCAL* differences (3.0), revealing a small difference between current and historical mortality. The gradual and continuous mortality improvements over most of the century in Northern-Europe explain the low levels of period and cohort mortality compared with other HLCs.

For Western-central European countries vs. HLCs, the range of *TCAL* differences was about 4 years. Only Switzerland, the Netherlands, and the UK experienced higher *TCAL* than other HLCs in 2010. The overall picture of the group showed an important difference between the range in life expectancy gap (2.6) and the range of *TCAL* differences (3.6), revealing the one year difference between current and historical mortality, when Western-central Europe is compared with other HLCs.

The range of *TCAL* differences between Eastern-European countries and other HLCs was more than 7 years. The highest *TCAL* difference was between Russia and other HLCs, about 11 years. Comparisons between life expectancies also reveal higher mortality of all Eastern-European countries compared with other HLCs in 2010. It is interesting to note that considering only the current mortality, the gap is even higher for Russia, Ukraine, Belarus, Latvia, Lithuania, and Bulgaria when compared with other HLCs in 2010. Probably, some past mortality improvements in these countries captured by *TCAL*, and not considered by the e_0, explains this higher disparity in e_0.

The *TCAL* values can also be compared among countries with the same starting and ending point of mortality series. For instance, countries with complete cohort mortality series in 2010, like all Nordic countries, can be compared. Among countries with complete cohort mortality information, Sweden and Switzerland are the leading countries with the highest *TCALs*, about 3 years more than Italy. Similar comparison can be made with a subgroup of Eastern-European countries with mortality series from 1949 to 2010.

4.2. Age- and cohort-contribution to the longevity differentials

To further understand the difference in cohort survival we present the age-cohort decomposition of the survival difference of all cohorts present in 2010. To exemplify our results, Figures 1-5 compare one country of each group with other HLCs. Figure 1 refers to a Non-European country, with Japan as the selected country; Figure 2 presents Spain from Southern-Europe; Figure 3 shows Norway from Northern-Europe; Figure 4 includes Germany as a country from Western-central Europe; and Figure 5 presents the Eastern-European country Ukraine. In the Appendix, the results for other countries and for each group are shown in Figures 1A, 2A, 3A, 4A and 5A.

These Figures show the Lexis surface for the cumulative age-cohort contributions to the difference in *TCALs* between the selected country and other HLCs. Each data point (age-*x* and time-*t*) in these figures represents the cumulative difference in cohort survival up to that specific age-*x* and year-*t*. Negative values are associated with higher HLCs survival.

Among all countries, Japan had the highest e_0 in 2010. The Japanese survival advantage is shown by both life expectancy gap (2.49) and *TCAL* difference (2.06) compared with other HLCs. Figure 1 expands this comparison, revealing a great survival advantage of all Japanese cohorts over age 60 in 2010. Moreover, this figure shows how the survival advantage of these Japanese cohorts born in the second quarter of the 20th century are gradually achieved by 2010, when mortality data from 1947 onwards are taken into account. The Japanese cohorts born from the mid-1940s to the late-1950s face a particular survival disadvantage from birth to the age attained in 2010. The youngest Japanese cohorts, those born after 1960, experienced higher survival from birth until 2010. The higher mortality experienced in the past by the oldest Japanese cohorts explains the lower gap in *TCALs* compared with the life expectancy gap.

[Figure 1 about here]

The Spanish e_0 was 1.53 years higher than that of other HLCs in 2010. Conversely, the *TCAL* difference reveals a Spanish survival disadvantage, about one year. Figure 2 shows the higher mortality at younger ages for all Spanish cohorts born before 1980 compared with other HLCs. This high infant/child mortality lasts until 2010. This figure also reveals more recent cohort developments: lower infant/child mortality in Spain than in other HLCs. These recent mortality improvements are also observed at other ages and explain the higher e_0 in Spain. However, these improvements are too recent to translate into a favorable gap in *TCALs* for Spain in 2010.

[Figure 2 about here]

The Norwegian survival advantage is revealed by both life expectancy gap (0.52) and *TCAL* difference (1.95) compared with other HLCs. Figure 3 shows the survival advantage at younger ages of all Norwegian cohorts compared with other HLCs. For Norwegian cohorts born after 1920 this lower infant/child mortality lasts until 2010. However, the survival advantage at younger ages of Norwegian cohorts born before 1920 has been lost by the age attained in 2010, reducing the overall cohort survival advantage of Norway. This higher mortality of Norwegian cohorts over age 90 in 2010 explains the lower gap in life expectancy than the gap in *TCALs*.

[Figure 3 about here]

The German *TCAL* lagged behind other HLCs by 2/3 of a year in 2010. Regarding the e_0, Germany lagged behind other HLCs by 1/3 of a year. Figure 4 reveals, for the window of observation from 1950s to 2010, that the German cohorts born before the 1950s have gradually lost their survival advantage by 2010. However, the German cohorts born after 1990 experienced higher survival from birth up to the age attained in 2010. This recent cohort development explains the lower gap in e_0 when compared with the gap in *TCALs*.

[Figure 4 about here]

The high Ukrainian mortality is shown by both life expectancy gap (10.24) and *TCAL* difference (9.14) compared with other HLCs. All Ukrainian cohorts experienced higher mortality than their counterparts in other HLCs in 2010 (Figure 5). Figure 5 shows how the survival disadvantage at younger ages of the Ukrainian cohorts has gradually increased by 2010. Only the

Ukrainian cohorts born between 1960 and the early-1970s face a particular survival advantage at younger ages. However, this survival advantage was gradually lost by 2010. Figure 5 reveals some past cohort survival advantages in Ukraine only considered by the *TCAL* and not taken into account by the e_0. Therefore, current mortality comparison reveals a worse mortality situation in Ukraine than when historical mortality information is considered.

[Figure 5 about here]

5. Discussion

Our results revealed some cohort mortality conditions masked by current mortality comparisons.

For the Non-European group, the survival advantage for cohorts born after the late-1940s was gradually lost by 2010 (Figure 1A). The higher levels of premature deaths (below age 65) in Non-European countries, like the US and New Zealand, compared with Italy, Switzerland, and some Nordic countries possibly reduced the overall survival advantage of the group compared with other HLCs (Cayotte and Buchow 2009; OECD 2011). Special attention was paid to Japan (Figure 1). We revealed great mortality improvements in Japan during the first decades after World War II for almost all cohorts present in 2010. In our window of observation, only the Japanese cohorts born in the mid-1940s faced higher mortality at younger ages when compared with other HLCs. The mortality effects of World War II probably explain this high infant/child mortality in Japan (Johansson 1987). Our decomposition also showed that the mortality effects of the war have been present for a long time in these Japanese cohorts. It remains to be seen whether this disadvantage will influence the future mortality of these cohorts at ages beyond 60. Conversely, Japanese cohorts born between 1950 and 1960 have gradually lost their survival disadvantage at younger ages until 2010. Examining mortality at older ages, Japan has experienced the highest rates of mortality improvements at old ages between the 1970s and 1980s.(Kannisto et al. 1994). We revealed how the Japanese survival advantage at older ages has gradually been achieved until now.

From the late-20th century, mortality at younger ages has decreased sharply in Southern-Europe, leading to a big increase in life expectancy at birth. Southern-Europe ranks high in terms of life expectancy compared with Northern-Europe, a region known by very low levels of mortality (Guillot and Canudas-Romo, 2016). However, the use of *TCAL* suggested the opposite. Considering the mortality progress over several decades, the low mortality levels of Northern-Europe compared with Southern and Western-central Europe are revealed.

The overview of the decomposition of the *TCAL* difference between Northern-Europe and other HLCs is shown in Figure 3A. Northern-Europe led the process of mortality decline, which started at young ages (Hill 1990; Bengtsson and Ohlsson 1994). However, at the turn of the 19th century infant/child mortality began to fall across the continent. Thus, a certain degree of convergence to lower mortality levels can already be detected in the first decades of the twentieth century (Vallin and Meslé 2004). *TCAL* revealed a reduction of the survival advantage of Nordic cohorts born after the 1960s compared with other HLCs. Whereas, Southern and Western-central European cohorts born in the late-20th century experienced an increasing survival advantage when compared with other HLCs. This convergence in mortality between these groups corresponds to a more broad demographic confluence observed in the last century (Wilson, 2011)

Another aspect revealed by *TCAL* was the survival disadvantage at older ages of Nordic cohorts born before 1930 compared with other HLCs (Figure 3A). Our decomposition showed how the survival advantage of cohorts aged over-80s in 2010 had gradually been lost. In the first half of the 20th century, Northern-Europe held the highest rates of mortality improvements for ages 80-99 (Kannisto et al. 1994). However, from the 1990s, Japan assumed this position, leading the country to the world highest expectation of life (Kannisto et al. 1994; Oeppen and Vaupel 2002). Northern-Europe has higher levels of alcohol consumption and tobacco use than Japan (WHO 2014, WHO 2015) that possibly increased the mortality differences at older ages between them.

The overview of Western-central group (Figure 4A) revealed a survival disadvantage at older ages of Western-central cohorts born before 1930 compared with other HLCs, as well as in Northern-Europe. Special attention was paid to Germany (Figure 4). The German reunification has played an important role in mortality changes in the country (Nolte et al. 2000). Immediately following reunification, due to the changes in diet, alcohol consumption and medical care, mortality sharply decreased in East Germany (Nolte et al. 2000). We showed that German cohorts born after the reunification, in 1990, experienced higher survival than other HLCs from birth up to the age attained in 2010. However, these improvements are too recent to overcome the overall period and cohort survival disadvantage by 2010.

Eastern-Europe is a region known by high mortality levels. After 1950, Eastern-Europe experienced important gains in life expectancy (Meslé et al. 2002). However, from the mid-80s the mortality situation changed in countries governed by communist regimes, where the health crisis hampered the survival progress (Meslé 2002). Despite continuous reductions in infant/child mortality, most of these countries experienced increase in adult mortality (Meslé et al. 2002; Shkolnikov and Nemtsov 1997). Our decomposition revealed that the mortality improvements at younger ages of Eastern-European cohorts born after 1960 compared with other HLCs were gradually lost by 2010 (Figure 5A). Only for Eastern cohorts born between 1960 and the late 1970s mortality improvements at first ages reach adulthood. This effect was probably triggered, in former USSR, by the anti-alcohol campaign addressed to adults, and launched by Gorbachev in the late 1980s (Shkolnikov and Nemtsov 1997), when cohorts born during the 1960s achieved young-adult ages.

6. Conclusion

Mortality differences between countries indicate potentials for public health intervention in order to eliminate and control avoidable mortality gaps in the future. We complement studies of mortality gaps by adding the cohort survivals comparisons. Moreover, the age- and cohort-contributions to the difference in *TCALs* reveal the differential survival trajectories of cohorts, showing exactly in which ages and for which cohorts survival differences appear.

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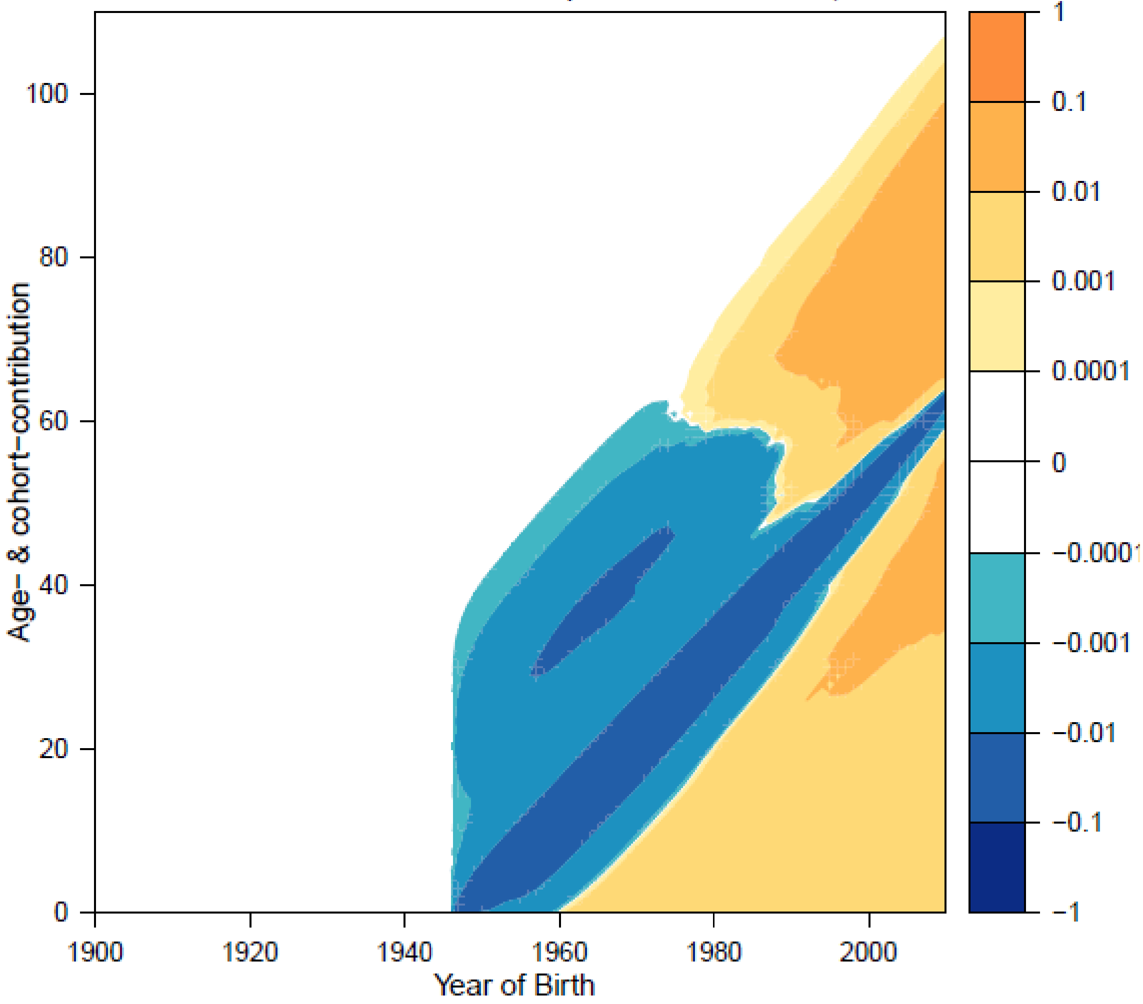
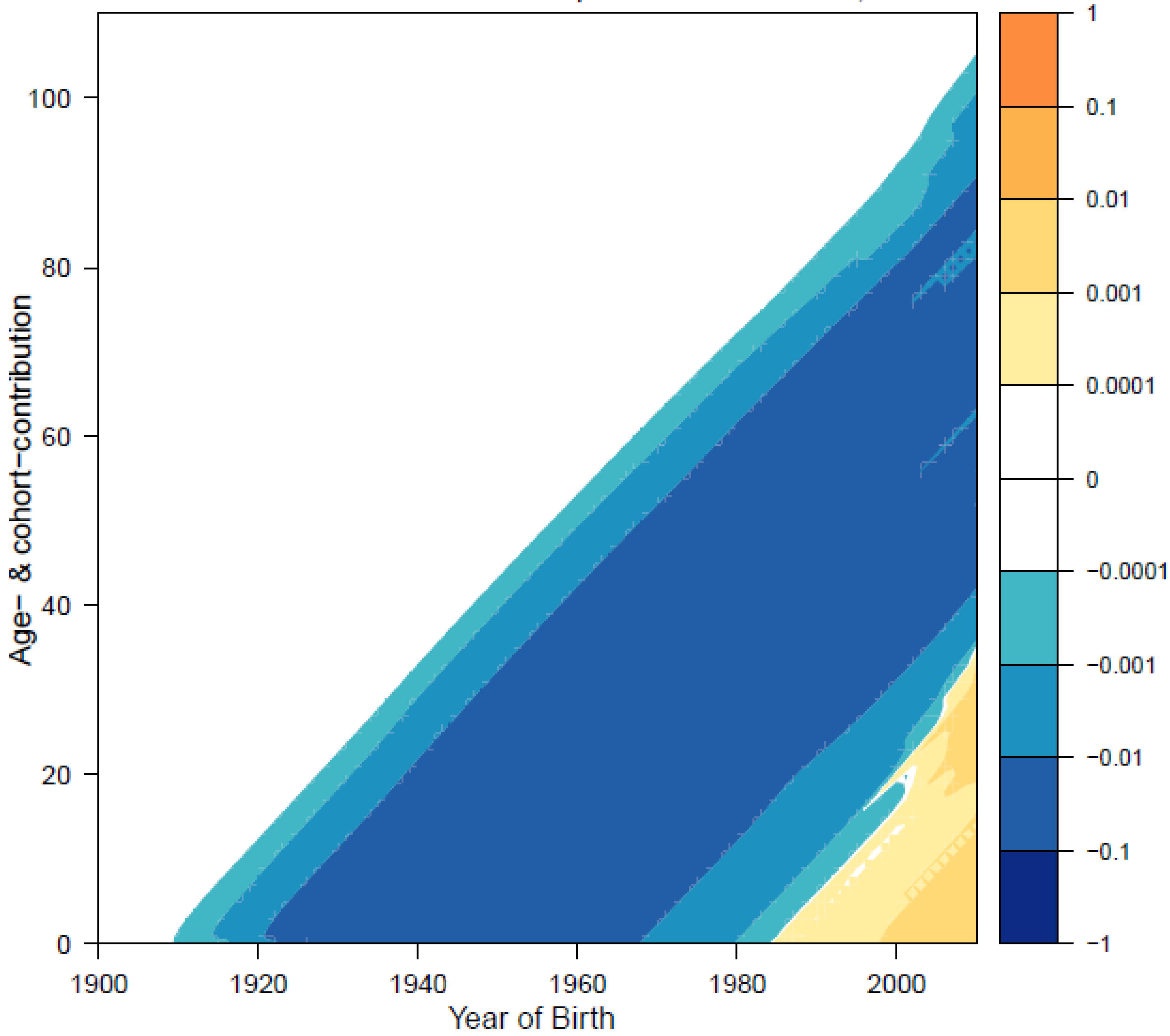
Figures

Figure 1 − Lexis surface for the cumulative age and cohort contributions to the difference in TCALs between Japan and other HLCs, 1947−2010.



Note:Negative values correspond to higher HLCs survival.
Source: HMD data and authors'own calculation.

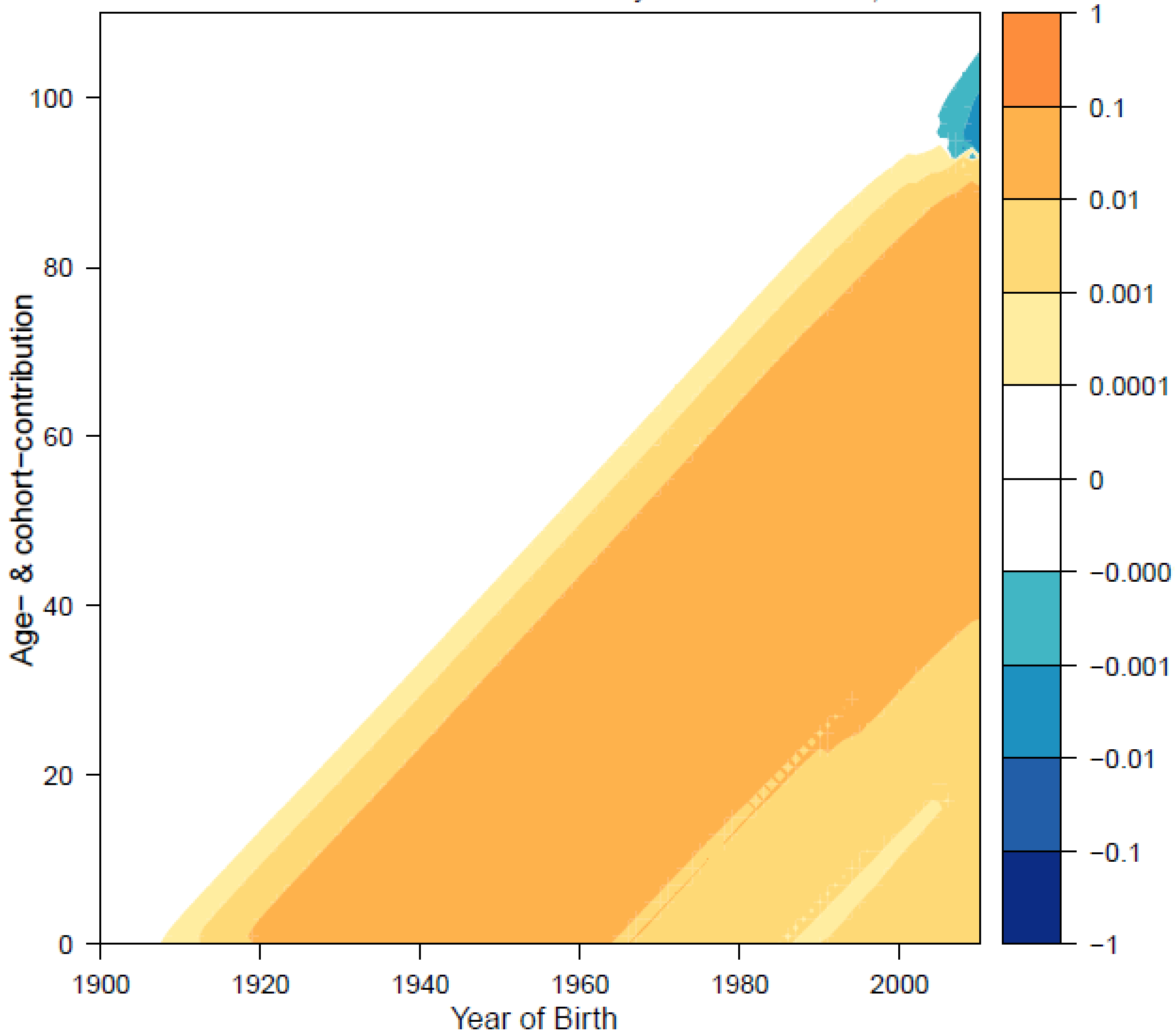
Figure 2 − Lexis surface for the cumulative age and cohort contributions to the difference in TCALs between Spain and other HLCs, 1900−2010.



Note:Negative values correspond to higher HLCs survival.

Source: HMD data and authors'own calculation.

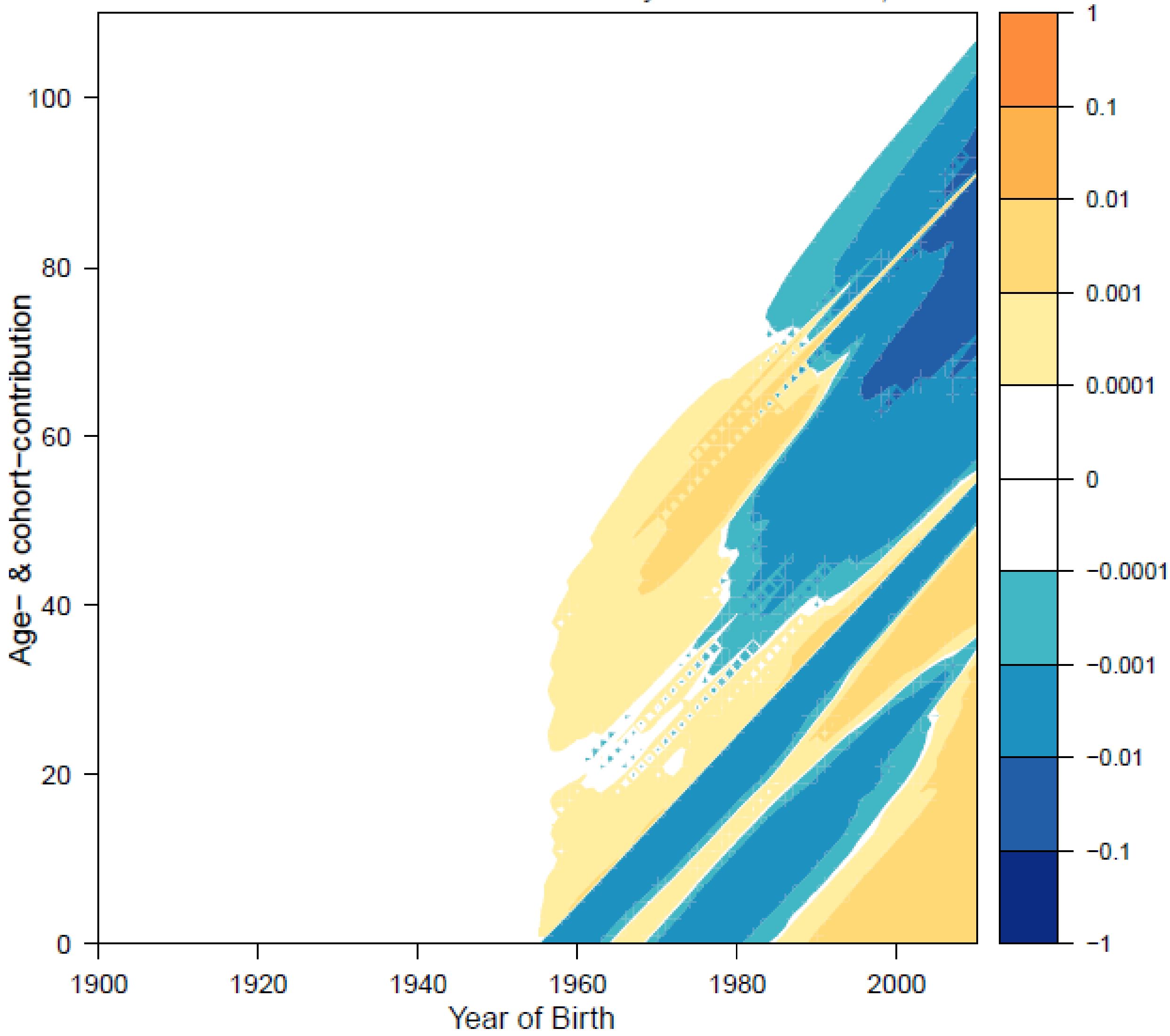
Figure 3 − Lexis surface for the cumulative age and cohort contributions to the difference in TCALs between Norway and other HLCs, 1900−2010.



Note:Negative values correspond to higher HLCs survival.

Source: HMD data and authors'own calculation.

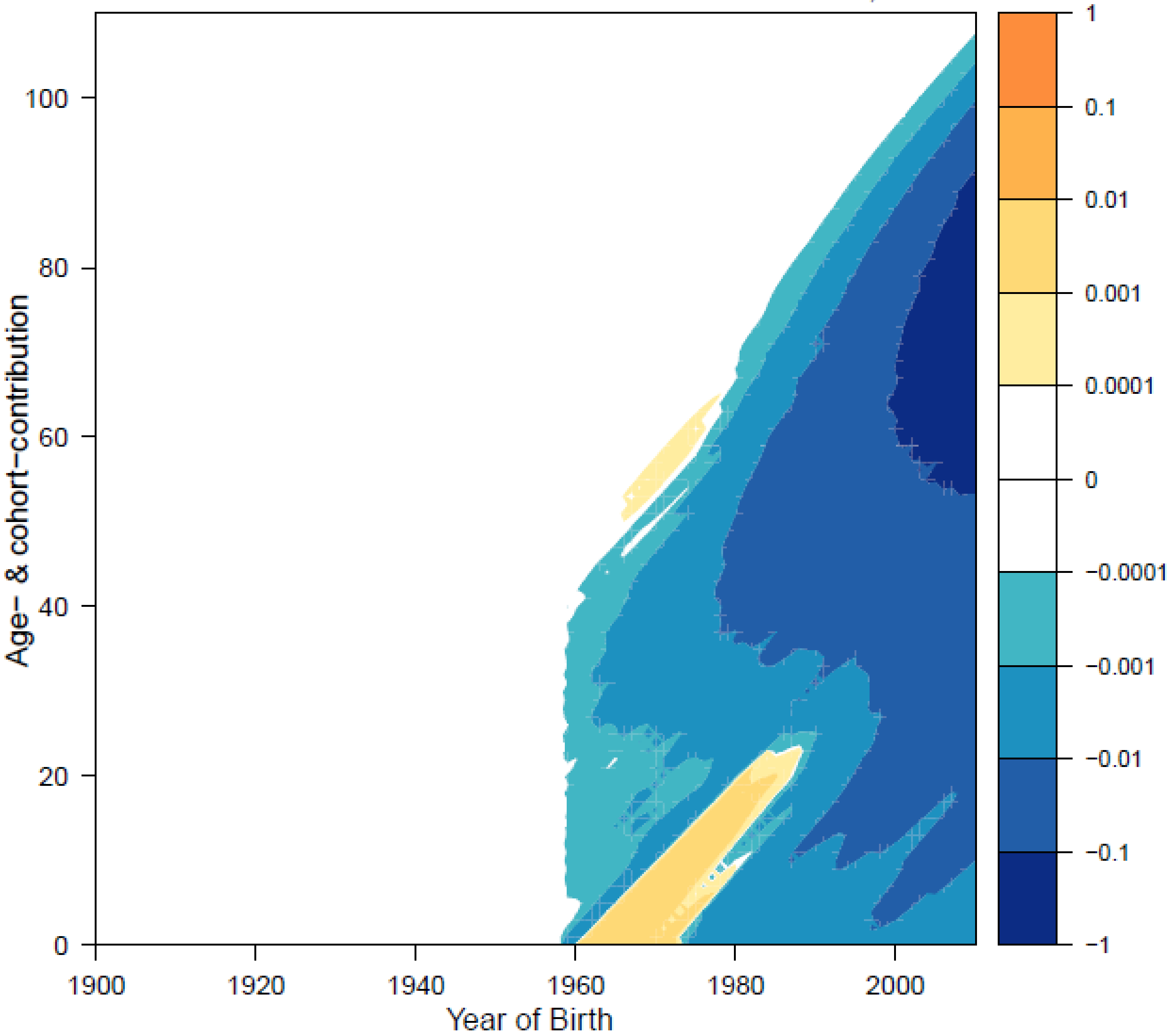
Figure 4 − Lexis surface for the cumulative age and cohort contributions to the difference in TCALs between Germany and other HLCs, 1956−2010.



Note:Negative values correspond to higher HLCs survival.

Source: HMD data and authors'own calculation.

Figure 5 − Lexis surface for the cumulative age and cohort contributions to the difference in TCALs between Ukraine and other HLCs, 1959−2010.



Note:Negative values correspond to higher HLCs survival.

Source: HMD data and authors'own calculation.

Appendix

Table 1A - Countries included in the analysis, and their start (Y_1) and end year (Y_n) of mortality series, regional Group, life expectancy at birth ($e^0(Y_n)$), *TCAL* and differences to the high longevity countries' $TCAL_{HLC}$ for female population.

Country/Group - X	Years Y_1* - Y_n**	Group	$e^0(Y_n)$	$TCAL_X$	$TCAL_{HLC}$***	$TCAL_{HLC}$ - $TCAL_X$
Japan	1947 - 2010	1	86.30	82.71	80.41	-2.30
Australia	1921 - 2010	1	84.25	80.51	78.43	-2.09
Canada	1921 - 2010	1	83.51	79.29	78.43	-0.86
New Zeland	1948 - 2008	1	82.34	79.70	80.15	0.45
United States	1933 - 2010	1	81.21	78.34	79.21	0.87
Group 1	**1921 - 2010**	**-**	**83.02**	**79.05**	**78.43**	**-0.62**
Italy	1900 - 2010	2	84.24	77.36	78.24	0.88
Spain	1908 - 2010	2	85.01	77.38	78.24	0.86
France	1900 - 2010	2	84.69	79.63	78.24	-1.39
Greece	1981 - 2010	2	83.17	82.47	82.63	0.16
Portugal	1940 - 2010	2	83.04	76.09	79.78	3.69
Group 2	**1900 - 2010**	**-**	**84.52**	**77.84**	**78.24**	**0.40**
Iceland	1900 - 2010	3	83.84	80.11	78.24	-1.87
Sweden	1900 - 2010	3	83.47	80.44	78.24	-2.20
Norway	1900 - 2010	3	83.15	80.14	78.24	-4.91
Finland	1900 - 2010	3	83.24	78.66	78.24	-0.42
Denmark	1900 - 2010	3	81.33	77.51	78.24	0.73
Group 3	**1900 - 2010**	**-**	**82.73**	**79.02**	**78.24**	**-0.78**
Switzerland	1900 - 2010	4	84.39	80.83	78.24	-2.59
Netherlands	1900 - 2010	4	82.72	79.42	78.24	-1.18
Luxembourg	1960 - 2009	4	83.18	80.53	81.08	0.55
Austria	1946 - 2010	4	83.15	79.97	80.41	0.45
United Kingdom	1922 - 2010	4	82.35	78.32	78.47	0.15
Germany	1956 - 2010	4	82.71	80.42	81.07	0.65
Ireland	1950 - 2009	4	82.23	79.05	80.51	1.46
Belgium	1919 - 2010	4	82.65	78.16	78.35	0.19
Group 4	**1900 - 2010**	**-**	**81.70**	**78.54**	**78.24**	**-0.30**
Czech Republic	1950 - 2010	5	80.64	77.87	80.75	2.88
Estonia	1959 - 2010	5	80.55	77.13	81.24	4.11
Poland	1958 - 2009	5	79.92	77.53	81.03	3.50
Slovakia	1950 - 2009	5	79.15	76.38	80.51	4.13
Hungary	1950 - 2009	5	78.23	75.13	80.51	5.38
Bulgaria	1948 - 2010	5	77.25	74.49	80.51	6.02
Lithuania	1959 - 2010	5	78.74	77.07	81.24	4.17
Latvia	1959 - 2010	5	77.42	75.84	81.24	5.40
Belarus	1959 - 2010	5	76.49	75.28	81.24	5.97
Ukraine	1959 - 2010	5	75.19	74.28	81.24	6.97
Russia	1959 - 2010	5	74.79	73.53	81.24	7.71
Group 5	**1948 - 2010**	**-**	**75.38**	**73.38**	**80.23**	**6.85**
HLCs	**1900 - 2010**	**-**	**83.13**	**78.24**	**-**	**-**

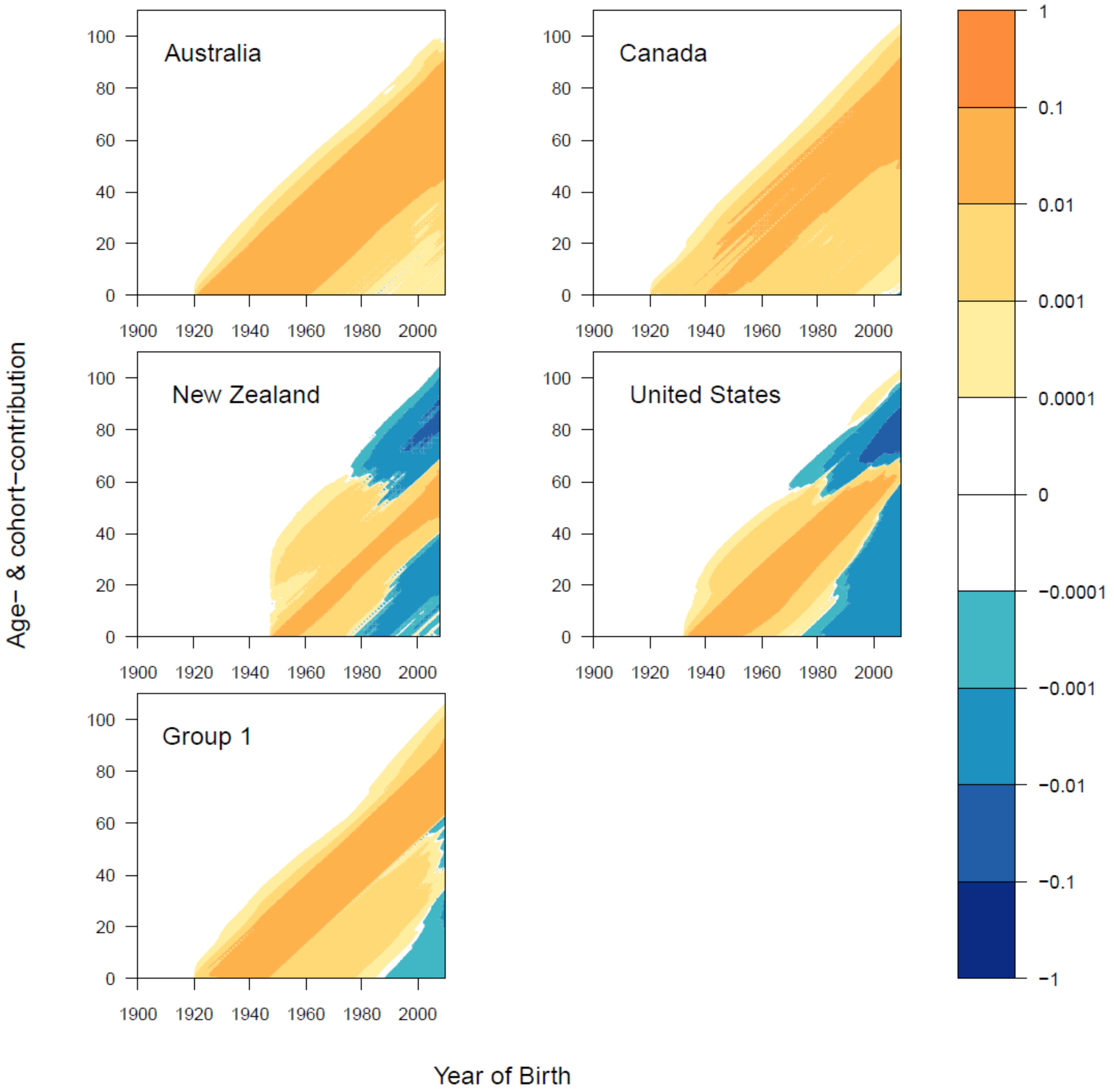
Source: authors's calculation, based on HMD data. *Notes:* * Y_1=The earliest year of the mortality series.** Y_n= The latest year of the mortality series. ****TCAL* for the other HLCs is calculated based on the earliest and latest year of the mortality series of the country/group-X. The group values are calculated similar to the HLCs based on average death rates for the earliest and latest year of the countries. Countries are listed as in Table 1.

Table 1B - Countries included in the analysis, and their start (Y_1) and end year (Y_n) of mortality series, regional Group, life expectancy at birth ($e^0(Y_n)$), *TCAL* and differences to the high longevity countries' $TCAL_{HLC}$ for male population.

Country/Group - X	Years Y_1*	Years Y_n**	Group	$e^0(Y_n)$	$TCAL_X$	$TCAL_{HLC}$***	$TCAL_{HLC}$ - $TCAL_X$
Japan	1947 -	2010	1	79.56	75.90	74.22	-1.68
Australia	1921 -	2010	1	79.87	75.08	72.54	-2.54
Canada	1921 -	2010	1	79.17	73.79	72.54	-1.25
New Zeland	1948 -	2008	1	78.37	74.62	73.89	-0.73
United States	1933 -	2010	1	76.37	72.51	73.07	0.56
Group 1	**1921 -**	**2010**	**-**	**77.55**	**73.05**	**72.54**	**-0.51**
Italy	1900 -	2010	2	79.49	72.13	72.46	0.33
Spain	1908 -	2010	2	79.01	71.40	72.48	1.08
France	1900 -	2010	2	78.04	72.22	72.48	0.26
Greece	1981 -	2010	2	77.88	77.49	76.92	-0.57
Portugal	1940 -	2010	2	76.74	69.15	73.58	4.43
Group 2	**1900 -**	**2010**	**-**	**78.25**	**71.60**	**72.48**	**0.88**
Iceland	1900 -	2010	3	79.73	75.52	72.48	-3.05
Sweden	1900 -	2010	3	79.51	75.55	72.48	-3.08
Norway	1900 -	2010	3	78.84	74.59	72.48	-2.11
Finland	1900 -	2010	3	76.72	71.43	72.48	1.05
Denmark	1900 -	2010	3	77.12	72.72	72.48	-0.25
Group 3	**1900 -**	**2010**	**-**	**78.24**	**73.43**	**72.48**	**-0.96**
Switzerland	1900 -	2010	4	80.05	75.04	72.48	-2.56
Netherlands	1900 -	2010	4	78.78	74.31	72.48	-1.83
Luxembourg	1960 -	2010	4	77.94	74.18	74.91	0.72
Austria	1946 -	2010	4	77.70	73.30	74.22	0.92
United Kingdom	1922 -	2010	4	78.37	73.65	72.57	-1.08
Germany	1956 -	2010	4	77.67	74.22	74.90	0.68
Ireland	1950 -	2009	4	77.24	73.91	74.27	0.37
Belgium	1919 -	2010	4	77.38	72.09	72.51	0.42
Group 4	**1900 -**	**2010**	**-**	**78.04**	**73.03**	**72.48**	**-0.55**
Czech Republic	1950 -	2010	5	74.43	70.74	74.56	3.81
Estonia	1959 -	2010	5	70.83	65.76	75.10	9.34
Poland	1958 -	2009	5	71.48	68.66	74.84	6.18
Slovakia	1950 -	2009	5	71.73	67.99	74.27	6.28
Hungary	1950 -	2009	5	70.21	66.33	74.27	7.95
Bulgaria	1948 -	2010	5	70.31	67.48	74.32	6.83
Lithuania	1959 -	2010	5	67.54	65.74	75.10	9.36
Latvia	1959 -	2010	5	67.43	64.48	75.10	10.62
Belarus	1959 -	2010	5	64.60	63.97	75.10	11.13
Ukraine	1959 -	2010	5	65.20	63.53	75.10	11.57
Russia	1959 -	2010	5	62.95	61.07	75.10	14.03
Group 5	**1948 -**	**2010**	**-**	**64.36**	**62.57**	**74.00**	**11.43**
HLCs	**1900 -**	**2010**	**-**	**77.78**	**72.48**	**-**	**-**

Source: authors's calculation, based on HMD data. *Notes:* * Y_1=The earliest year of the mortality series.** Y_n= The latest year of the mortality series. ****TCAL* for the other HLCs is calculated based on the earliest and latest year of the mortality series of the country/group-X. The group values are calculated similar to the HLCs based on average death rates for the earliest and latest year of the countries. Countries are listed as in Table 1.

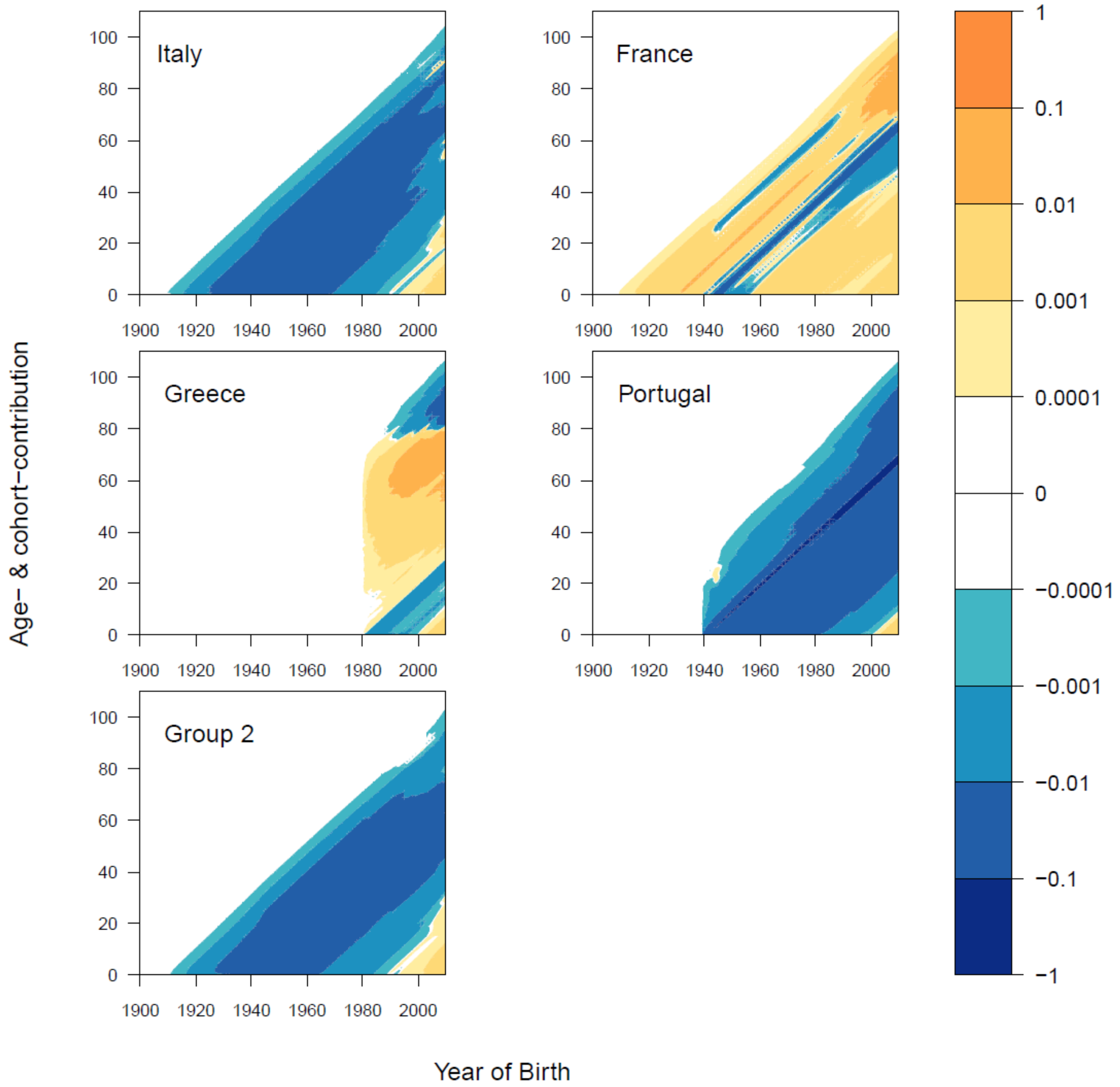
Figure 1A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Non-European countries and other HLCs.



Note: Negative values correspond to higher HLCs survival.

Source: HMD data and authors' own calculation

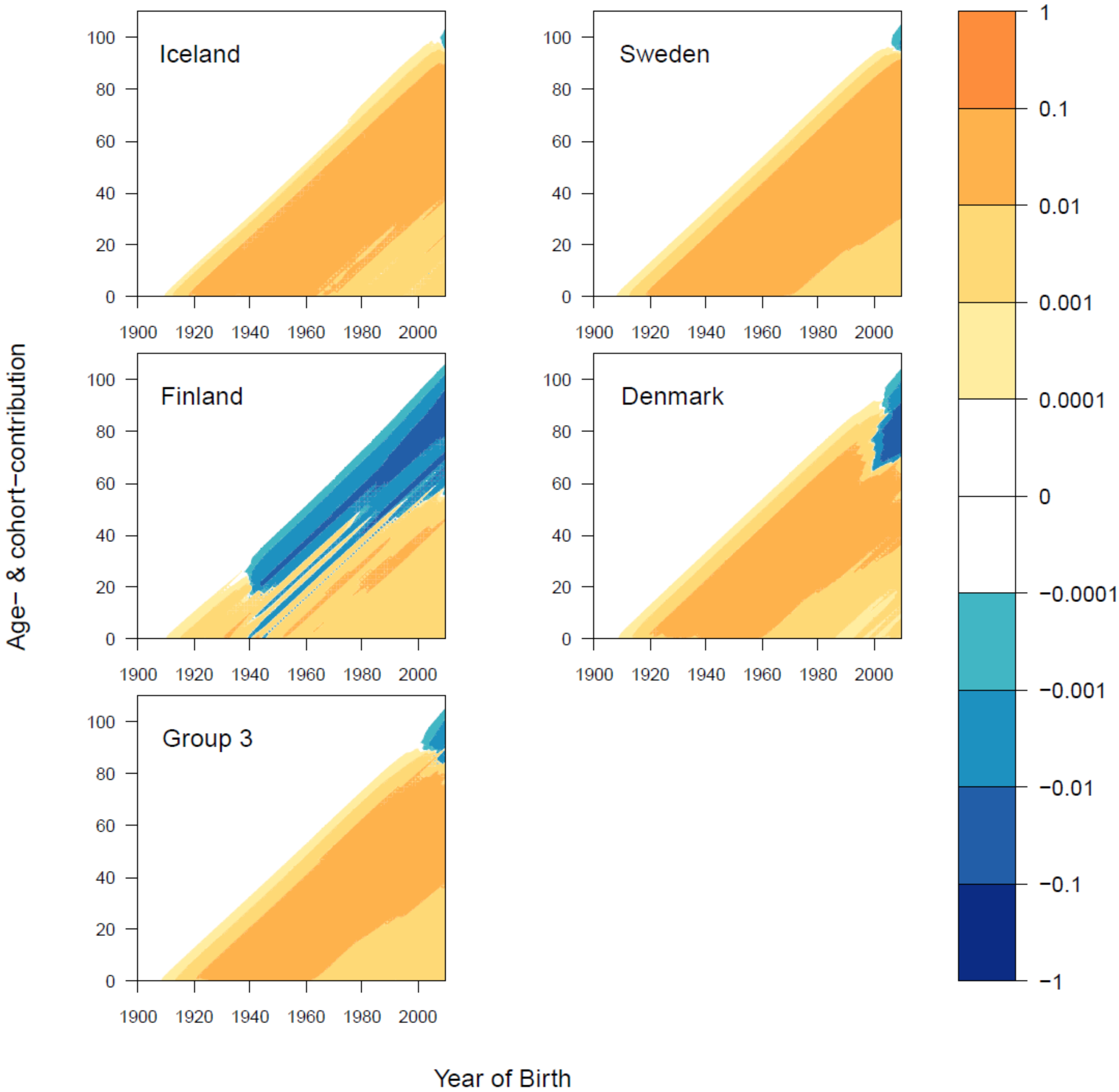
Figure 2A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Southern-European countries and other HLCs.



Note: Negative values correspond to higher HLCs survival.

Source: HMD data and authors' own calculation

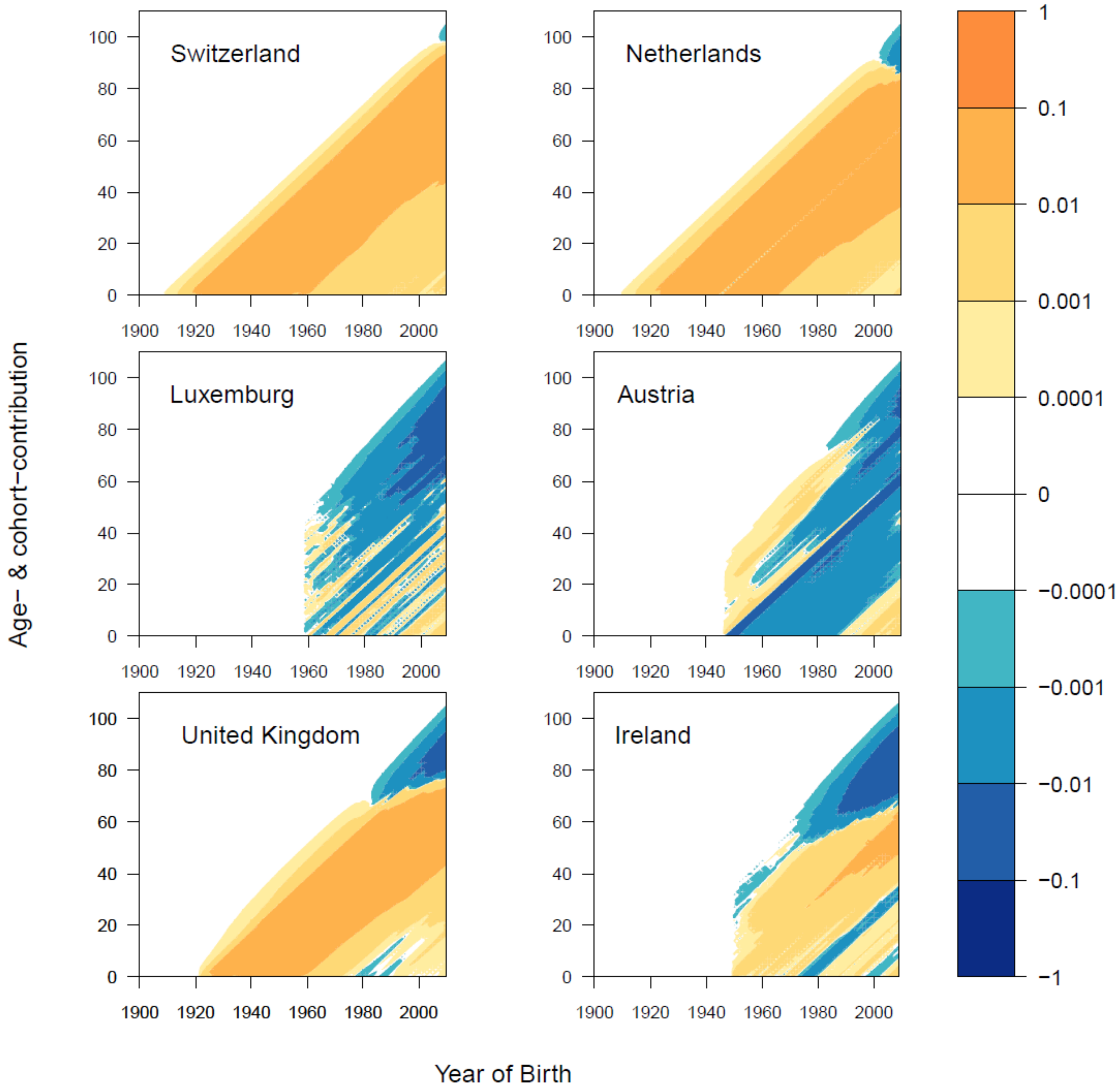
Figure 3A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Nordic countries and other HLCs.



Note: Negative values correspond to higher HLCs survival.

Source: HMD data and authors' own calculation

Figure 4A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Western-central European countries and other HLCs.

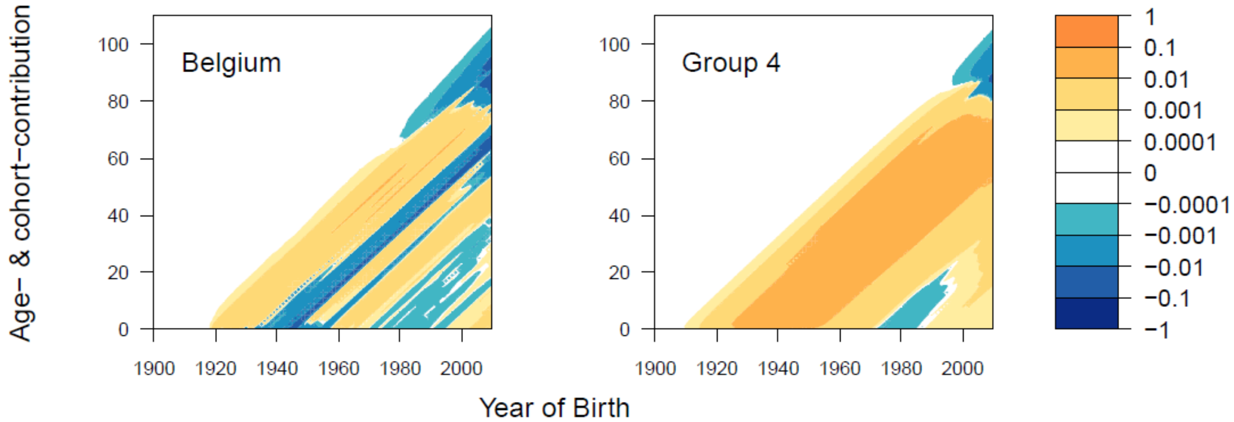


(Continue)

Note: Negative values correspond to higher HLCs survival.

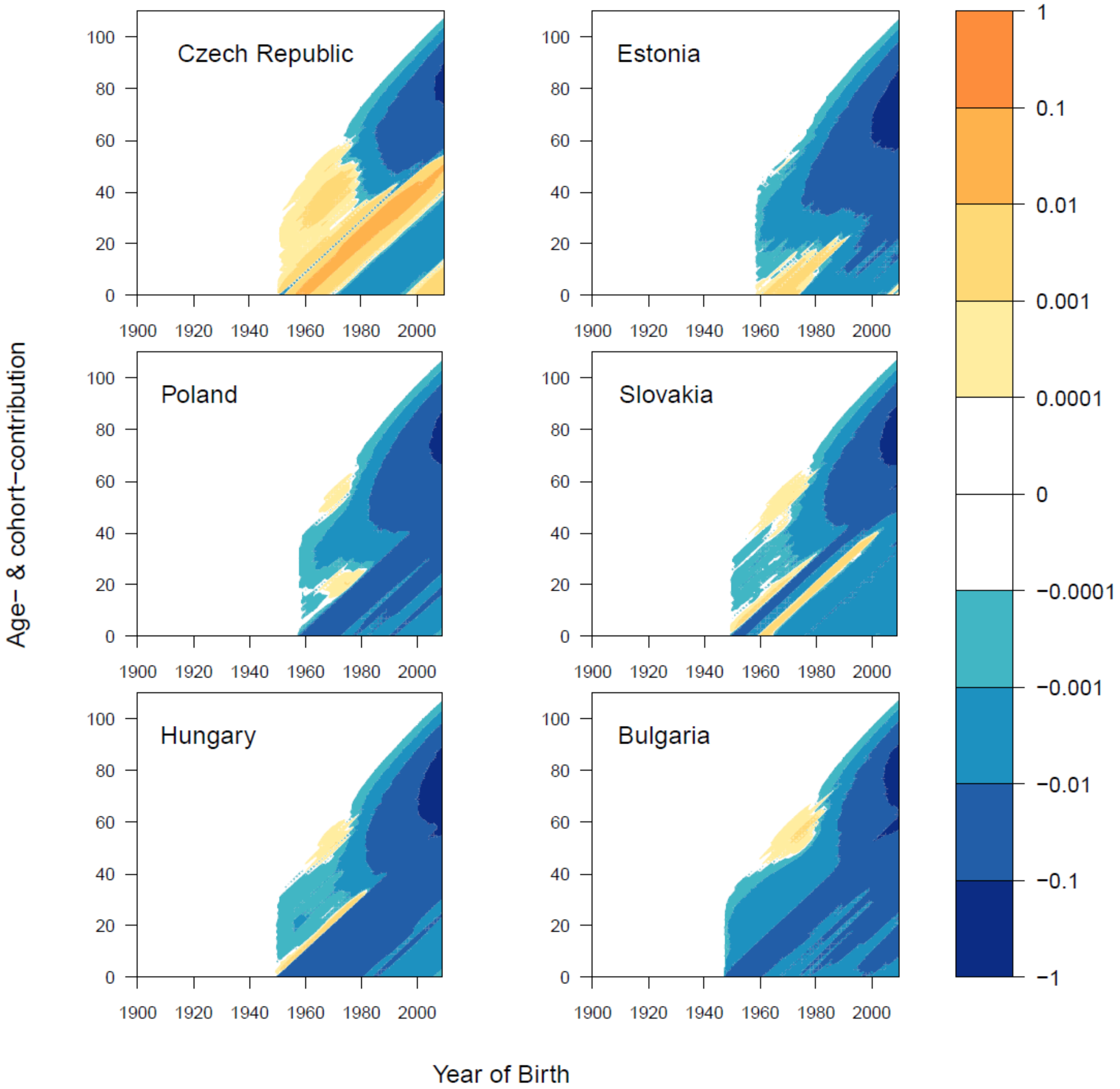
Source: HMD data and authors' own calculation

Figure 4A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Western-central European countries and other HLCs.



Note: Negative values correspond to higher HLCs survival.
Source: HMD data and authors' own calculation

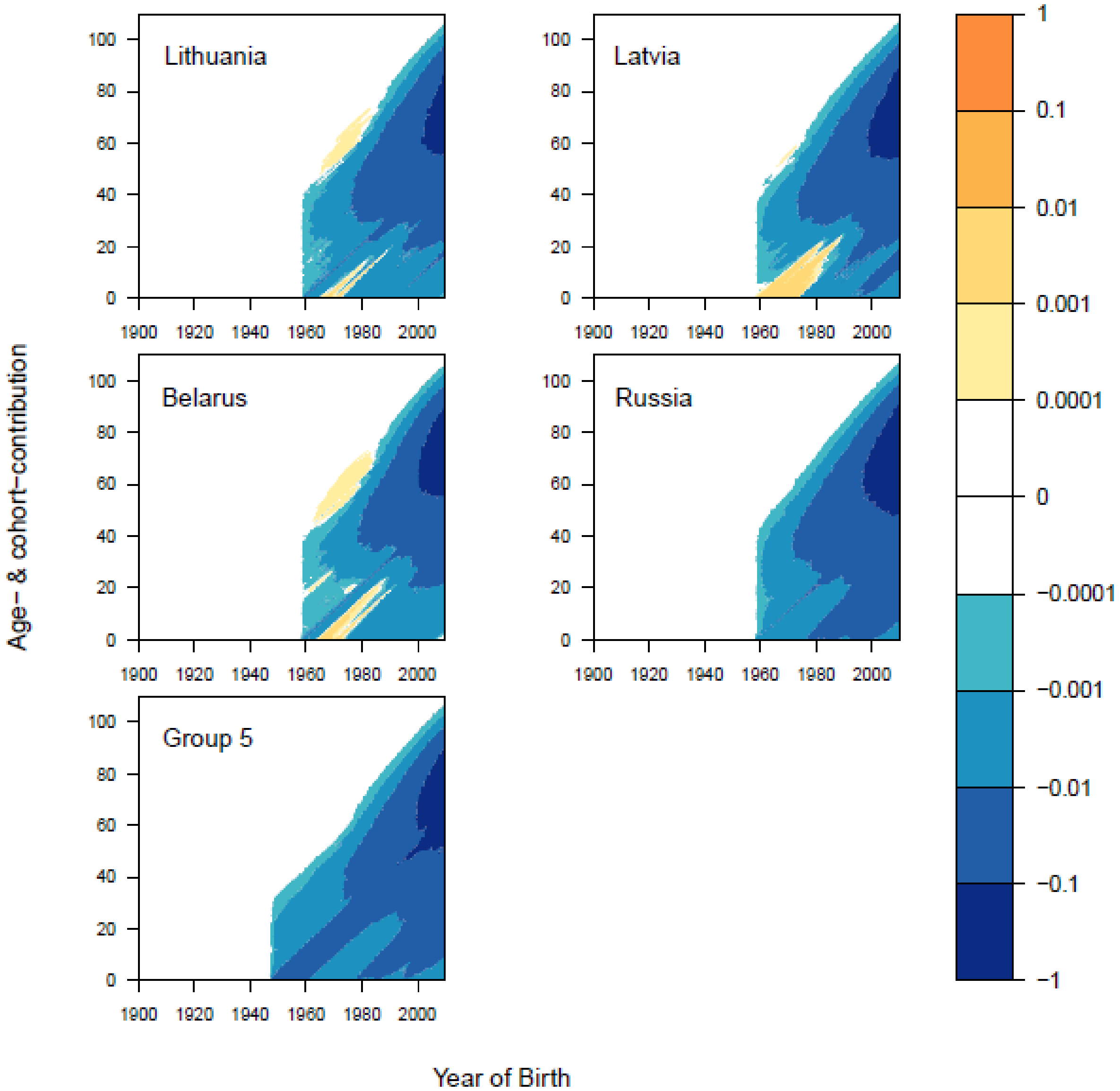
Figure 5A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Eastern-European countries and other HLCs.



(Continue)

Note: Negative values correspond to higher HLCs survival.
Source: HMD data and authors' own calculation

Figure 5A – Lexis Surface of the cumulative cohort contributions to the difference in TCALs between Eastern-European countries and other HLCs.



Note: Negative values correspond to higher HLCs survival.

Source: HMD data and authors' own calculation