BASIC COHORT MORTALITY ANALYSIS AT HIGHER AGES: AN ANALYSIS OF THE RECTANGULARISATION PROCESS BASED ON COHORTS BORN IN 1890–1910 IN THE CZECH REPUBLIC AND FRANCE [1)]

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ABSTRACT

The aim of the article is to conduct a basic mortality analysis of persons aged 60 and over, focusing on the cohort perspective. The Czech Republic and France were selected for comparison. Owing to data availability the analysis covered cohorts born in 1890–1910, where for each of the two countries it was possible to use data only from one particular source. Moreover, these cohorts can be assumed to be extinct today. People in these cohorts reached the age of 60 and over starting in the year 1950, so it is also possible to study significant period effects on cohort data caused by developments in the second half of the 20th century. This approach makes it possible to study mortality development at the highest ages while using the concept of rectangularisation of the survival curve, or mortality compression, as theoretical basis of the analysis. The assumptions of this concept were not however fully verified for any of the studied populations.

Keywords: mortality, cohort life tables, period life tables, limit of the life span, life expectancy, rectangularisation process

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INTRODUCTION AND THE AIM OF THE STUDY

The longitudinal approach to mortality analysis has only started to be applied more frequently in recent decades owing primarily to the increasing availability of data necessary for such analysis. This approach enables a better understanding of the internal dynamics of demographic phenomena in real cohorts, unlike the cross-sectional perspective, which refers to fictitious (hypothetical) cohorts determined by period fluctuations. This fact has also been noted by *Ryder* (1965: 845): 'The cohort record is not merely a summation of a set of individual histories. Each cohort has a distinctive composition and character

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reflecting the circumstances of its unique origination and history.' For example, wars or epidemics may be taken as factors that leave a specific (negative or positive) imprint on the future health of individuals from the same birth cohort.

This article will focus on the basic cohort analysis of adult mortality (applied to selected already extinct cohorts) using cohort life tables (constructed for people ages 60 and over). The aim is not only to illustrate the development but also to introduce briefly and empirically verify some selected features of the concept of the rectangularisation of the survival curve or the compression of ages at death (mortality compression), which will be briefly introduced in the theoretical section of the article. This concept was chosen as the theoretical basis of the analysis because it involves assumptions about the theoretical limits of the human life span. Analysis of the selected cohorts (1890–1910) will cover the second half of the 20th century. Thanks to that it will be possible to trace the consequences of the mortality stagnation that was observed in the Czech Republic (especially among males) between the 1960s and the 1980s in cohort mortality patterns among people ages 60 and over. The situation and development in the Czech Republic will be compared with France, the country traditionally used for such comparisons because of the similar post-war mortality situation (see Figure 2).

Because cohort life tables are not yet very common or available even in some demographically developed countries, cohort life tables that have already been constructed and are publically available will be referred to. The possibilities of constructing complete cohort life tables for the Czech Republic will also be briefly evaluated. This will be followed by a discussion of some specific features relating to the construction and state of this type of life table in the Czech Republic. Then theoretical concepts related to the assumptions about the limits of the human lifespan, specifically the hypothesis of rectangularisation and mortality compression, will be described. This hypothesis will be verified using cohort data for the Czech Republic and France. Verification of this hypothesis could open a possible way to searching the existence and accessibility of some limit of the human lifespan.

The analysis of the rectangularisation of the survival curve (or analysis of the compression or expansion of mortality), and the search for the theoretical limits of the life span in general, are fundamental parts of the work of actuaries, medical doctors, and epidemiologists, but also historians, economists, sociologists, commercial and analysts in public, and other researchers and experts. Cohort life tables make it possible, among other things, to better evaluate the needs of the pension and health care systems and to better judge the social conditions of different age groups (*Shumanty*, 2012).

THE AVAILABILITY OF COHORT LIFE TABLES INTERNATIONALLY AND IN THE CZECH REPUBLIC

Some demographically developed countries have already constructed and published complete cohort life tables (see Appendix 1). In some of these countries, they are the outcome of scientific research, in others they were prepared and issued by the national statistics offices. Several cohort life tables are available from the Human Mortality Database[2)] (see Appendix 2), currently one of the most frequently used sources of demographic data on mortality. In most cases, these are countries where the necessary data are available and cover long enough periods of time.

In the Czech Republic, despite the fact that raw data exist and are of relatively good quality, no complete set of cohort life tables has yet been constructed. An estimate of the mortality of only one birth cohort (1875) and only for females was published in Základy demografie (*Pavlík et al.,* 1986: 180–182) and a partial look (based on data for the period 1950–1990) at cohort mortality resulted from the research project Analysis of mortality in the Czech Republic: causal models of mortality changes in generations and the international comparative analysis (*Rychtaříková et al.*, 1994). An elementary cohort analysis relating at least partially to the Czech Republic was also done as part of a poster presentation at the European

2) www.mortality.org

Population Conference in Vienna in 2010 (*Mazouch – Tesárková*, 2010) and in Stockholm in 2012 (*Mazouch – Hulíková Tesárková*, 2012). At present the construction of cohort life tables is the goal of a grant project financed by the Czech Science Foundation (*'Cohort life tables for the Czech Republic: data, biometric functions, and trends'*, GAČR project no. P404/12/0883).

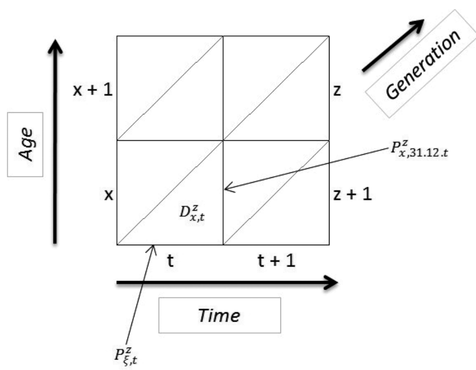
THE CONSTRUCTION OF COHORT LIFE TABLES

One of the most important and most difficult tasks involved in constructing cohort life tables is to prepare the necessary mortality data. Czech demographic statistics are of good quality and were so also in the past. However, for different time periods the data for cohorts have to be drawn from different sources (from printed publications for the period before the world wars, from the reconstruction or estimation of data for the period of the First and Second World Wars, or from post-war printed or electronic sources, and in recent years individual data can also be used), which are often classified in a different manner (in the earliest period there are third sets of events (squares) in the Lexis diagram; from the year 1895 there are elementary sets, triangles, of events; in recent years there exist individual data). For a proper cohort mortality analysis, the data should be available at least in elementary sets (triangles), so they can then be reclassified into the first classes of deaths. The first set of data is defined by one cohort (year of birth; z), one year of age (x) and two calendar years (t, $t + 1$), (see Figure 1).

Other problems can arise from the fact that the number of deaths and the exposed population are not necessarily tied to the same population or do not correspond to the same territory (this occurred especially during the world wars in the Czech Republic).

Given all the aforementioned complications with data reconstruction, and given the fact that the aim is to study mortality patterns at higher ages only, in this article cohort life tables were constructed only for people ages 60 and over. All the data used come from the years after the Second World War. Thanks to this, only one source of data was used for the Czech Republic – the Czech Statistical Office.[3] All the data on deaths were originally classified into the elementary sets (triangles) and then reclassified into the first sets of data. The number of inhabitants at the end of the year was recalculated to get the number of persons at the exact age (see Figure 1). The number of inhabitants alive at exact age ξ ($P^z_{\xi,t}$) was estimated as the number of survivors at the end of year t ($P^z_{x,31.12.t}$) plus the number of deaths at age x during year t corresponding with generation z ($D^z_{x,t}$). In this calculation the effect of migration was not included because data in the necessary structure are not available for both the countries. Moreover, because of the construction of the probabilities of dying (Figure 1) we do not expect any significant effect of migration to mortality (especially at ages above 60).

Figure 1: **Lexis diagram – recalculation of the number of inhabitants at the end of the year into the number of inhabitants at the exact age**



$$P^z_{\xi,t} = P^z_{x,31.12.t} + D^z_{x,t}$$

When the number of people at the exact age was calculated for all the years included and all the ages 60 and over, it was possible to calculate the probability of dying for cohort z, at age x during years t and $t + 1$ (i.e. for the first sets of events).

3) In the analytical part of the article data were drawn from printed (Pohyb obyvatelstva) or online publications (http://www.czso.cz/csu/redakce.nsf/i/casova_rada_demografie).

$$q^z_{x;t,t+1} = \frac{D^z_{x,t} + D^z_{x,t+1}}{P^z_{\xi,t}}$$

The values of the probabilities of death were then used as the basis for the life table. All the other table functions were calculated from this column and the table was constructed in the traditional manner (*Pavlík et al.*, 1986).

For France, data from the Human Mortality Database were used. The life tables were constructed in the same manner as those for the Czech Republic, with two exceptions. The first exception was the ending of the table. While the tables for the Czech Republic ended with an open interval of 100 or more years,[4)] tables from the Human Mortality Database (HMD) for France ended with the interval of 110 or more years. It must be said that the difference is almost invisible. Moreover, for graphs and further analyses, only completed ages from 60 to 99 are used. The other exception relates to the imputed data: while for the Czech Republic raw data were used to estimate the probabilities of death, for France the cohort probabilities were taken from the Human Mortality Database. In both cases, however, the data are classified into the first sets of events (*Wilmoth et al.*, 2007).

MORTALITY AT ADVANCED AGES – THEORETICAL BACKGROUND

In this article the life tables were constructed for people age 60 and over. One reason for this was already mentioned – the availability of data and the lack of any need to use multiple data sources. Another reason is connected with the fact that the study of mortality at higher or advanced ages gets more attention in association with pension and other social reforms. Moreover, while mortality at young ages is already very low, mortality development at higher ages (where mortality is still relatively high) is a source of a possible future rise in life expectancy. That is why there are many current studies of mortality at those ages (e.g. *Gavrilov – Gavrilova*, 2011 or *Wachter*, 1997).

Mortality development at higher ages is also an interesting field of study in itself. Many theories dealing with the subject exist. Most of them are closely related to deal with the assumption of the existence of some limit of the lifespan. Some of them are briefly introduced for example by *Vaupel* (1997). One of the earliest theories in this area was put forth by Buffon, according to whom 'each species has a characteristic maximum life span and that this life span is six or seven times the duration of the period of growth' (*Vaupel*, 1997: 18). Drawing on this assumption, *Gavrilov* and *Gavrilova* (1991) estimated that for humans the biological lifespan is 90–100 years. In other studies it is assumed that mortality probably reaches its maximum around the age of 110 (*Vaupel*, 1997). One of the best-known supporters and representatives of the idea of a fixed limit to the lifespan was *James Fries* (1980), who estimated the human lifespan limit to be around the age of 85. However *Vaupel* (1997) points out that many of the theories postulating a limit to the lifespan are based, above all, on assumptions and ideas rather than on empirical data.

For many demographers and biologists there remains the question of how to explain the observed mortality pattern at higher ages. One of the most important ideological trends is the study of the impact of population heterogeneity. According to the theory of heterogeneity, the structure of the population can lead formally to a deceleration at the end of the mortality curve (*Vaupel* et al., 1979; *Vaupel – Yashin,* 1985; *Hulíková Tesárková*, 2012a), as frailer individuals die at a younger age.

Many theoretical concepts of ageing are briefly introduced also by *Harris* (2009). When dealing with the possible limits of human life expectancy, he mentions, for example, the theory of vitalism, cellural mutation, the human machine theory, programmed obsolescence theory, and others. *Wilmoth* (1997) in his work defines three basic hypotheses related to the possible future development of mortality at older and the oldest ages: 'the limited-life-span hypothesis', 'the limit-distribution hypothesis' and 'the hypothe-

4) Except for the 1900 cohort, where data on survivors were available only up to the age 98 and for the open interval of ages 99 and over (Pohyb obyvatelstva v České republice v roce 1999, http://www.czso.cz/csu/redakce.nsf/i/casova_rada_demografie_2009_1990). For this cohort the figures present data only up to the age 98.

sis of compression or rectangularisation' (for details, see *Wilmoth*, 1997 or *Hulíková Tesárková*, 2012b). The last-mentioned was selected as the theoretical basis for the analytical part of this article. The decision to choose this hypothesis was motivated by its overall popularity in mortality analysis and its suitability for describing general mortality trends represented by biometric functions.

The hypothesis of mortality compression or the rectangularisation of the survival curve is often presented as a separate demographic issue. In general, the principle of this hypothesis can be defined through the use of two different table functions. When the survival curve is used, the so-called rectangularisation process is studied. When the distribution of table deaths is used then the mortality compression is considered. *Fries* (1980) postulated that during positive mortality development both these processes can be observed at the same time, which means that decreasing mortality leads to the compression of mortality as well as to the rectangularisation of the survival curve. The reason for the co-occurrence of these two processes is the assumed existence of a fixed limit to human life. In the empirical analysis below we would like to study both these processes with the aim to verify or disprove their co-occurrence or the original assumptions of *Fries* (1980). This could be an important aspect in the search for possible ways of finding any evidence of a theoretical limit to the human life-span. The process of mortality compression can be formulated as a reduction of variance (variability) of ages at death (X) in a given population over time (*Wilmoth*, 1997; *Fries*, 1980):

$$Var\,(X,t_1) > Var\,(X,t_2) > \cdots > Var\,(X,t_n),$$

where $t_1 < t_2 < \cdots < t_n$ are particular moments in time. For the analysis the distribution of deaths is used.

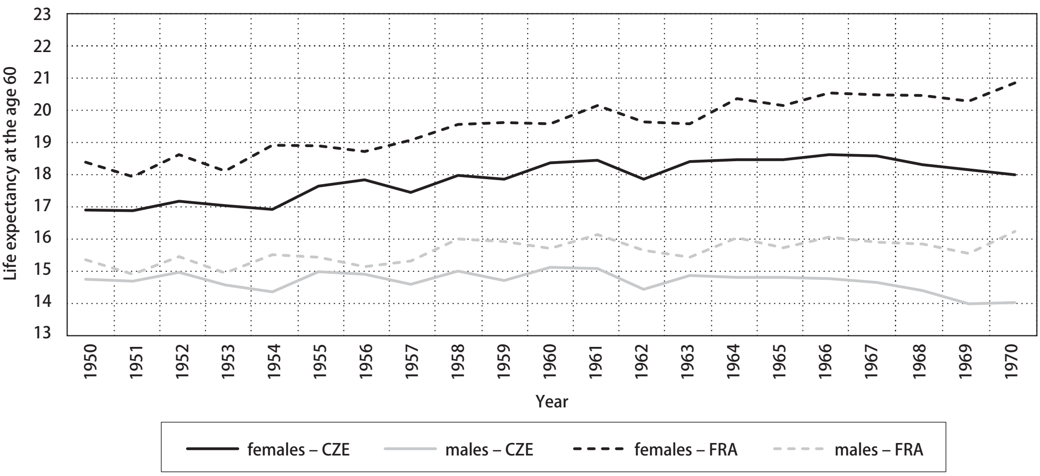
On the other hand, the process of the rectangularisation of the survival curve is based on the assumption that when mortality is decreasing the shape of the survival curve approaches that of a rectangle as a consequence of the higher concentration of survivors at higher ages.

The process of the rectangularisation or compression of mortality can be defined through many different indicators (*Hulíková Tesárková*, 2012b). In connection with the existence of a possible limit to the length of life, one assumption of this hypothesis is emphasised: that the compression reflects a convergence towards the potential maximal characteristic length of human life, which is reflected also in the shape of the survival curve (*Fries*, 1980). However, as *Wilmoth* (1997) noted, the only reduction in the variability of ages at death, or in the survival curve's increasingly rectangular shape, is not sufficient proof of the existence of the limit of life expectancy or human life. Along with the rectangularisation of the survival curve there can also occur a shift in the whole age distribution of deaths to higher ages and the variability of ages at death could remain almost stable or could even increase (*Wilmoth*, 1997; *Canudas-Romo*, 2008). Despite many reservations, analysis of the process of rectangularisation or compression itself can play an important role in the general analysis of mortality at the highest ages.

ANALYSIS OF SELECTED LIFE TABLE FUNCTIONS – COHORT LIFE TABLES FOR THE CZECH AND FRENCH POPULATION AT AGE 60 AND OVER

The analytical part of the article focuses on two countries: the Czech Republic and France. The reason for this is their similar total level of mortality and its developmental tends in the post-war period and their different development in the 1960s, 1970s and 1980s, where we can see a stagnation of mortality among Czech females and even worsening mortality among Czech males (when the mortality level is expressed, for example, as life expectancy at birth). On the other hand, in France improvements are visible throughout the period under observation. If we consider only the period 1950–1970 (corresponding with analyses below; Figure 2), the 1950s can be identified as the period when the developmental trend was similar for both Czech and French females and males. In the 1960s life expectancy at age 60 continued to increase for females in both countries, but the rate of increase was higher in France. For males we can see almost stagnation in France and a worsening in the Czech Republic. How this worsening and also the different developmental trends affected the cohort mortality of both sexes in both countries analysed will be shown in the next part of this article. To construct

Figure 2: **Development of the life expectancy at the exact age 60, period life tables, the Czech Republic, France, 1950–1970**



Source: Period life tables from the Human Mortality Database.

the cohort life tables for people at ages 60 and over the numbers of deaths were classified into the first set of events (according to the particular cohort, age and two calendar years). The root of the table (l_{60}) was set as equal to 100,000. Then the life tables were calculated in the traditional manner (described above).

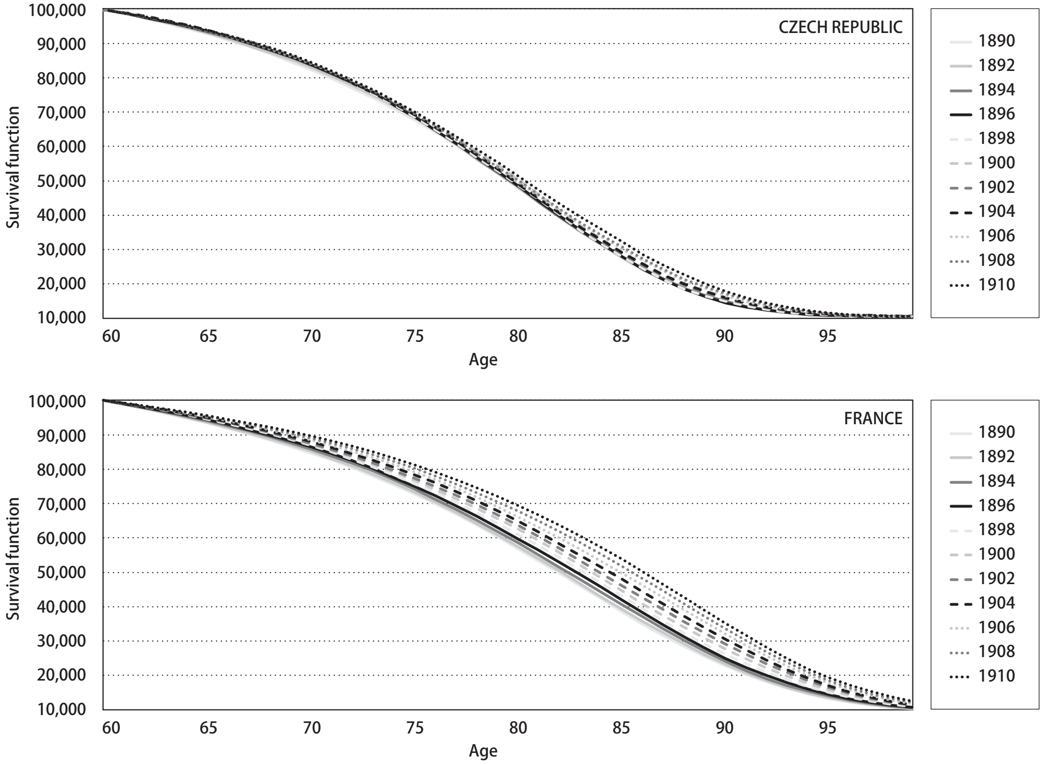
The aim of the analysis was to evaluate the changes at higher and the highest ages for males and females separately within the context of the mortality stagnation observable in the second half of the 20th century in the Czech Republic and to identify differences from France, representing a developed country with more stable mortality development. If the results prove the assumption that the survival curve is getting more rectangular and at the same time that the curve of the density of deaths is getting more compressed without any change in the overall age-level of the curve, then the hypothesis of rectangularisation or compression could be taken as verified for the countries and cohorts involved in the study. Verification of the hypothesis would also leave open the possibility that there is a fixed limit to the human life-span (*Fries*, 1980). Later in the article, it will be also shown what the consequences of overall mortality stagnation for cohort data at higher ages in the Czech population were.

The studied cohorts were born between 1890 and 1910; people in the oldest cohort were 60 years old in 1950, and people in the youngest cohort were 60 years old in 1970. All these cohorts can now (at the time of this analysis) be considered to be extinct (the tables ended with the open age interval of 99 and over for the Czech Republic[5)] and 110 and over for France, but for the figures only ages up to 98 were used so that the values for both countries would be comparable). It is clear that members of the cohorts in this analysis went through different periods of history and this had an effect on the mortality conditions of the cohorts.

According to Figures 3 and 4, we can conclude that the development of the cohort mortality in the Czech Republic was significantly different for males and for females. The male trend in the Czech Republic clearly reveals how period effects influenced cohort patterns. The survival curve tended to decrease (worsen) in consecutive cohorts. This would be a sign of the process of derectangularisation – i.e. the process opposite to the rectangularisation which reflects mortality improvements (*Hulíková Tesárková*, 2012b). This would correspond with the mortality increase observed during the 1960s and 1970s in the Czech Republic

5) With the exception of the cohort born in 1900, where the last open interval included ages 98 and over.

Figure 3: **Survival function from the cohort life tables of the population at ages 60 and over, the Czech Republic (upper graph) and France (lower graph), females, cohorts 1890–1910**

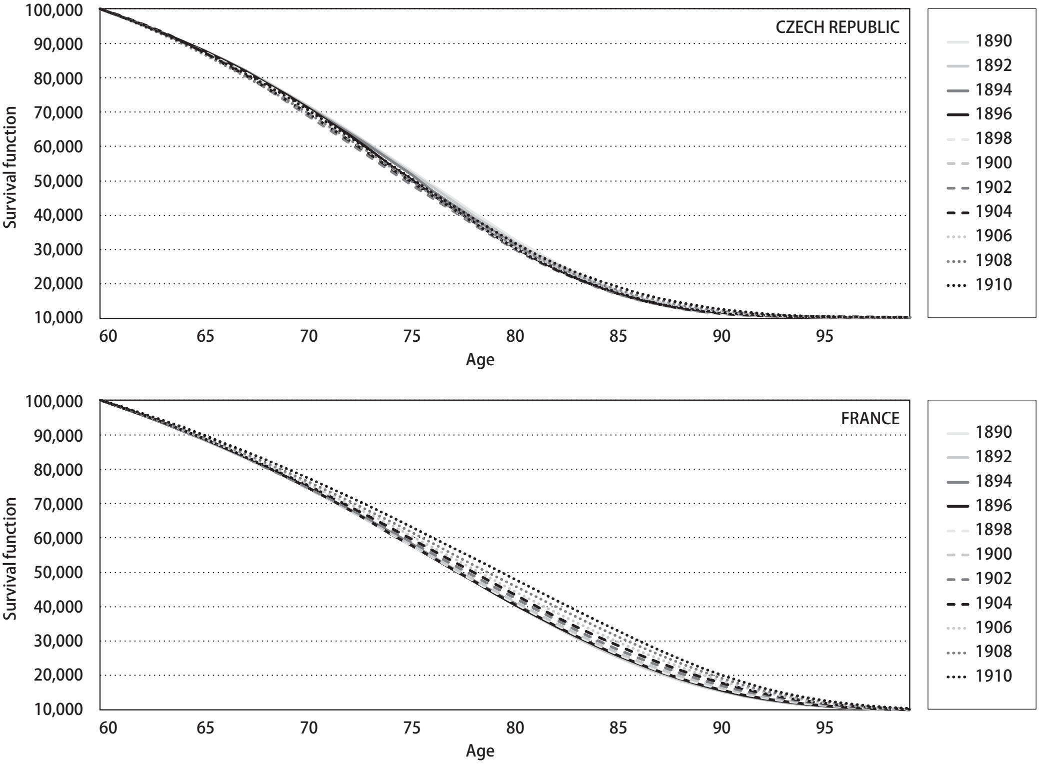


Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

and affected especially the population of males. Only in the youngest cohorts can we see some improvements at the highest ages (above the age of 84). That is proof of the significant influence of period changes during the second half of the 20th century (Figure 4). For France the picture is completely different also in the case of males. Although period mortality data show stagnation in the case of French males, in a cohort perspective we can observe an improving trend. So it could be said that the period effect (stagnation) did not influence the cohort pattern so significantly (especially among those ages 70 and over).

An interesting fact (which can be observed in Table 1) is the decreasing share of survivors from the exact age 60 to age 70 among males in the Czech Republic. This could be interpreted as a consequence of the mortality stagnation that occurred from the 1960s in the Czech population (especially males). Among males in France no such tendency can be seen (Table 2) and the share is increasing for the studied cohorts. The same could be concluded also for the proportion of survivors up to the ages 75, 80 or 85. Above these ages the probability of surviving from the age of 60 increases (with some variability) in time. Based on the results, mortality stagnation (and worsening mortality among males) during the second half of the 20th century affected also the population at higher ages (ca up to the age 85) in all the studied cohorts. For the Czech Republic, the cohort born in the year 1900 looks rather exceptional. The values of the proportions in Table 1 (and also those of other indicators below) for this cohort are influenced by the slightly higher probability of dying at a lower age (i.e. ca up to age 70) and the lower probability of dying at a higher age (i.e. ca 75 and more years) compared to subsequent and preceding cohorts. From the data it cannot be said what the reason for this special pattern

Figure 4: **Survival function from the cohort life table of the population at ages 60 and over, the Czech Republic (upper graph) and France (lower graph), males, cohorts 1890–1910**



Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

is (e.g. poor data quality), so this could be the subject of further discussion.

The situation is different for females. Females in the Czech Republic were not as affected by the negative development in the 1960s and 1970s as males, so the changes in the survival curve in time (Figure 3) seem to be more in accordance with the assumptions of the hypothesis of rectangularisation. What is interesting in this picture is the improvement at the highest ages, especially among the youngest cohorts. This is illustrated in Table 3. From Figure 3 we can assume that although overall mortality improved for consecutive cohorts (which is consistent with the assumptions of the hypothesis of rectangularisation), it is likely that the variability increased because the proportion of survivors to the highest ages is higher (Table 3). Almost the same thing can be seen among French females, but all the changes were more significant (shown also in Table 4). The increase in the variability of ages at death would contradict the expectations of the tested hypothesis. This can be evaluated using the curve of the distribution of table deaths (density of deaths). For the studied cohorts the function is shown in Figures 5 and 6.

As Figure 5 shows, for Czech females our assumption about rising variability could be taken as verified (although so far only based on a visual evaluation of the figures). Below it will be confirmed also by the numerical values of selected indicators (Figure 7). For French females it may seem that the concentration of deaths around the mode is similar for all the cohorts analysed, but the whole distribution has shifted to higher ages (an occurrence postulated, for example, by *Canudas-Romo*, 2008). It would be in contrary to the assumptions of the hypothesis of rectangularisation or compression. But this visual evaluation is not sufficient to make such conclusions,

Table 1: **Probability of surviving from the exact age 60 to the exact age x, males, Czech Republic, cohorts 1890–1910 (in %)**

	Age x:	70	75	80	85	90	95
Cohort	1890	68.54	47.35	25.06	8.48	1.44	0.04
	1891	69.21	47.46	24.89	8.30	1.41	0.06
	1892	68.49	46.74	24.26	8.21	1.40	0.08
	1893	68.02	46.33	23.71	7.90	1.25	0.07
	1894	68.05	46.23	23.41	8.02	1.13	0.05
	1895	68.01	45.13	22.80	7.80	1.19	0.03
	1896	67.92	44.60	22.44	7.49	1.18	0.09
	1897	67.06	43.69	22.14	7.12	1.29	0.07
	1898	67.36	44.01	22.45	7.20	1.23	0.08
	1899	66.65	43.24	22.00	7.11	1.22	0.09
	1900	65.93	43.57	23.24	8.16	1.96	0.16
	1901	66.08	43.23	21.80	6.79	1.19	0.13
	1902	65.35	42.94	21.95	7.39	1.40	0.16
	1903	66.00	43.67	22.27	7.38	1.35	0.19
	1904	66.15	43.91	22.39	7.88	1.57	0.16
	1905	65.92	43.61	22.27	7.99	1.65	0.22
	1906	66.09	43.96	22.47	8.31	1.73	0.23
	1907	66.11	44.05	22.93	8.32	1.93	0.21
	1908	66.33	44.20	23.36	8.86	2.16	0.20
	1909	67.11	44.91	24.08	9.63	2.50	0.23
	1910	67.26	44.94	23.98	9.76	2.56	0.22

Table 2: **Probability of surviving from the exact age 60 to the exact age x, males, France, cohorts 1890–1910 (in %)**

	Age x:	70	75	80	85	90	95
Cohort	1890	71.74	53.50	33.96	17.10	6.10	1.33
	1891	71.96	53.43	33.76	16.92	6.90	1.28
	1892	72.01	53.71	34.17	17.19	6.24	1.34
	1893	71.82	53.39	33.94	17.30	6.29	1.43
	1894	71.90	53.74	34.51	17.68	6.45	1.51
	1895	71.80	53.49	34.50	17.93	6.48	1.46
	1896	71.84	53.18	34.09	17.67	6.53	1.55
	1897	71.80	53.13	34.12	17.78	6.63	1.68
	1898	71.68	53.17	34.58	18.00	6.92	1.67
	1899	71.22	53.07	34.46	18.30	6.96	1.68
	1900	71.50	53.52	35.19	18.56	7.31	1.89
	1901	71.51	53.66	35.56	18.98	7.58	1.90
	1902	71.82	54.30	36.26	19.55	8.40	2.60
	1903	72.26	54.98	36.84	20.27	8.45	2.15
	1904	72.59	55.29	37.32	20.85	8.85	2.32
	1905	72.90	56.04	38.10	21.61	9.33	2.42
	1906	73.05	56.22	38.32	22.50	9.52	2.47
	1907	73.36	57.02	39.40	22.91	9.90	2.68
	1908	73.81	57.44	40.10	23.71	10.35	2.84
	1909	74.60	58.46	41.21	24.68	10.89	2.95
	1910	74.99	59.17	42.29	25.57	11.36	3.19

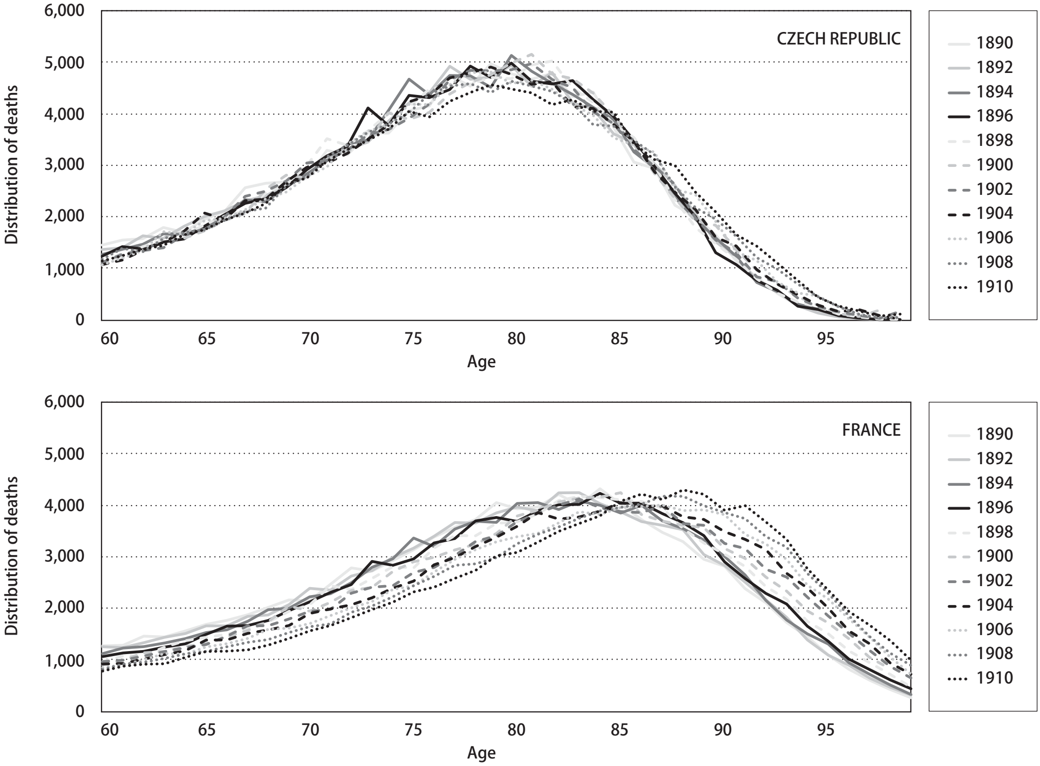
Table 3: **Probability of surviving from the exact age 60 to the exact age x, females, Czech Republic, cohorts 1890–1910 (in %)**

Age x:		70	75	80	85	90	95
Cohort	1890	80.05	63.69	41.45	18.70	4.84	0.36
	1891	80.35	63.68	41.42	18.58	4.56	0.33
	1892	80.81	64.38	41.69	19.34	4.71	0.33
	1893	81.30	64.44	41.63	19.04	4.44	0.34
	1894	81.60	64.85	42.05	19.23	4.91	0.46
	1895	81.75	64.61	41.81	19.63	4.66	0.40
	1896	81.88	64.68	42.14	19.26	4.49	0.45
	1897	81.92	64.48	42.03	19.35	4.73	0.44
	1898	82.06	64.63	42.41	19.28	4.92	0.55
	1899	81.92	64.39	42.19	19.29	4.98	0.53
	1900	82.17	65.67	44.21	20.48	6.09	0.75
	1901	81.84	64.61	42.72	19.76	5.48	0.73
	1902	81.90	65.31	43.10	20.30	5.70	0.81
	1903	82.43	65.99	43.29	20.59	6.22	0.84
	1904	81.86	65.47	42.71	20.74	6.09	0.85
	1905	82.10	65.75	43.19	21.04	6.50	1.01
	1906	82.18	65.71	43.40	21.74	6.72	1.04
	1907	82.30	65.55	43.88	22.34	7.18	1.00
	1908	82.32	65.68	43.96	22.58	7.48	1.00
	1909	82.46	65.89	44.65	23.44	7.88	1.13
	1910	82.51	66.32	45.32	24.15	8.23	1.17

Table 4: **Probability of surviving from the exact age 60 to the exact age x, females, France, cohorts 1890–1910 (in %)**

Age x:		70	75	80	85	90	95
Cohort	1890	83.09	70.05	52.38	32.25	14.97	4.39
	1891	83.56	70.44	52.77	32.45	15.14	4.44
	1892	83.72	70.63	53.09	33.01	15.47	4.66
	1893	84.06	71.30	53.77	33.92	15.93	5.02
	1894	84.38	71.62	54.34	34.54	16.34	5.18
	1895	84.67	71.67	54.81	35.24	16.78	5.41
	1896	85.08	72.43	55.56	35.99	17.25	5.68
	1897	85.19	72.74	55.97	36.51	17.83	5.97
	1898	85.56	73.27	56.99	37.34	18.64	6.40
	1899	85.64	73.66	57.67	38.08	19.48	6.81
	1900	85.93	74.34	58.73	38.96	20.26	7.25
	1901	86.17	74.70	59.49	40.00	21.30	7.63
	1902	86.19	75.06	59.93	40.60	21.86	7.91
	1903	86.63	75.64	60.59	41.67	22.62	8.37
	1904	86.80	76.15	61.29	42.69	23.44	8.48
	1905	86.92	76.57	61.93	43.54	24.42	8.96
	1906	87.26	77.08	62.62	44.64	25.17	9.39
	1907	87.69	77.99	63.86	45.97	26.07	9.79
	1908	87.91	78.24	64.53	46.82	26.80	10.10
	1909	88.27	78.91	65.64	48.24	27.90	10.65
	1910	88.62	79.33	66.27	49.14	28.55	11.06

Figure 5: **Distribution of deaths from the cohort life table, population at ages 60 and over, the Czech Republic (upper graph) and France (lower graph), females, cohorts 1890–1910**

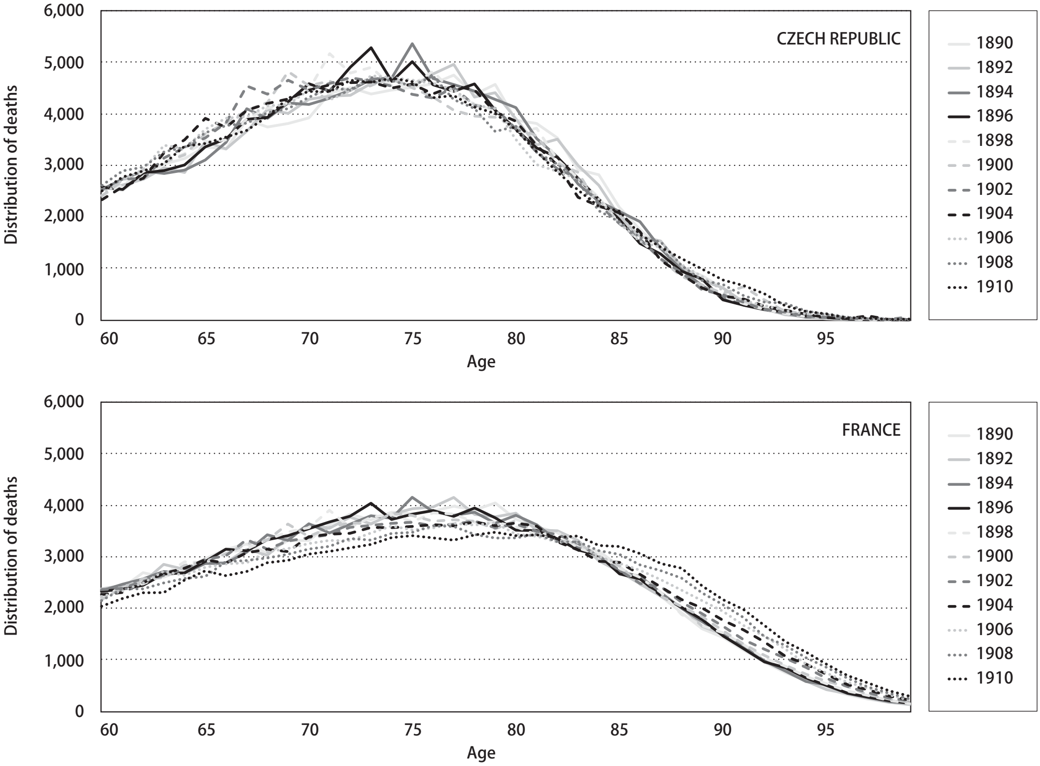


Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

because it does not involve the possible influence of a larger share of survivors (and logically also deaths) at the highest ages on the whole variability of the distribution. Further on in this analysis this fact will also be confirmed by quantitative analysis. From Figure 6 it seems that the variability for males is almost the same across all the Czech cohorts analysed. Only the several youngest cohorts can be taken as an exception, as in these cohorts the number of deaths increased at the highest ages, which could explain the increase in the variability of ages at death. For French males we can see both – rising variability of ages at death and a shift in the distribution to higher ages. Moreover, it is apparent that the variability of ages at death is clearly significantly higher for the French population than the Czech population, where deaths are visibly more concentrated around the mode. However, all the described changes of variability of ages at death must also be evaluated numerically.

For the purpose of this article we can use, for example, the interquartile range (IQR) as an indicator of variability of ages at death. This indicator is traditionally used in this type of analysis and it is also easy to calculate and interpret. The changes in variability could also be studied more in-depth using some other indicators – one of the best-known ones, for example, is the standard deviation of ages at death calculated only for ages above the mode ('standard deviation above the mode' in short). This measure can be used to reveal the changes in the variability of ages at death at the very oldest ages. It describes the changes at the end of the curve of the distribution of deaths. To use this indicator correctly, however, the cohort life tables would have to end at the same age so that the results would be comparable for both populati-

Figure 6: **Distribution of deaths from the cohort life table, population at ages 60 and over, the Czech Republic (upper graph) and France (lower graph), males, cohorts 1890–1910**



Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

ons studied. Moreover, this indicator is not directly connected to the hypothesis of mortality compression because it does not deal with the concentration of ages at death around the mode.

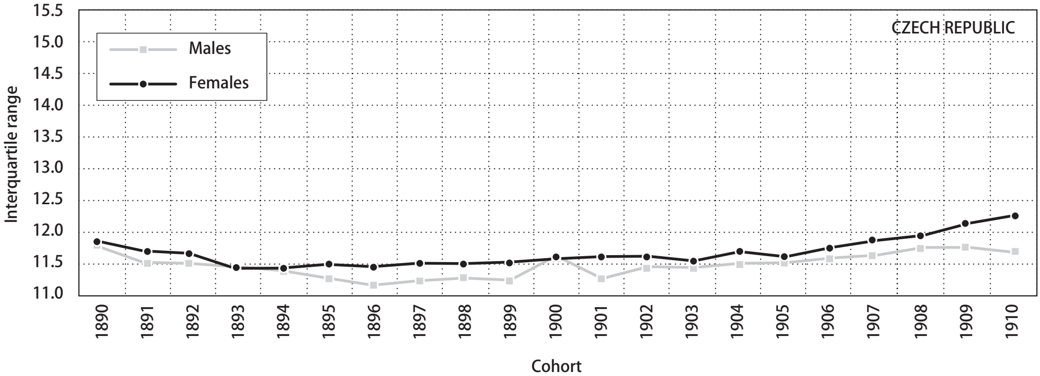
Another indicator (perhaps the best known one) dealing with the variability of ages at death is the index of entropy. This indicator expresses the rate of uncertainty in the studied mortality distribution and it is used often in population biology and in the analysis of the rectangularisation process (*Keyfitz – Caswell*, 2005; *Hulíková Tesárková*, 2012b). It can be calculated from the values of the survival curve according to *Keyfitz* and *Caswell* (2005: 80; with the necessary change of the symbols) as:

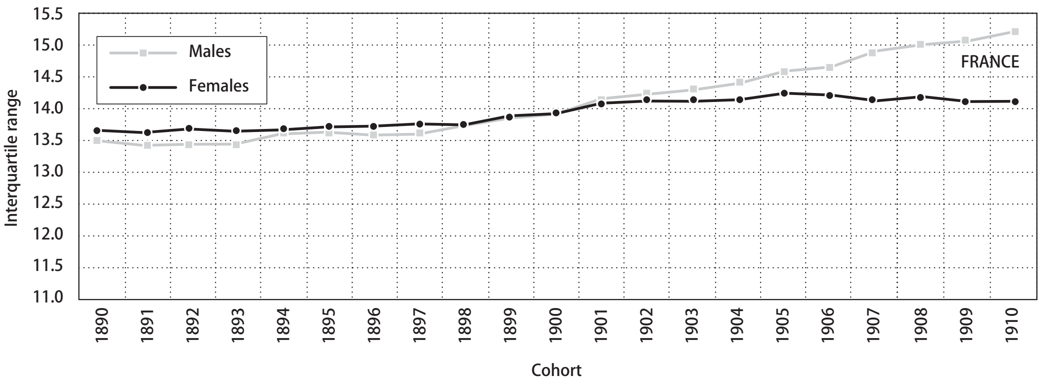
$$H = -\frac{\int_{60}^{\omega} [\log l(x)] * l(x)dx}{\int_{60}^{\omega} l(x)dx}$$

where H is the index of entropy, ω is the highest attainable age in the life table and $l(x)$ is traditionally the survival curve. If entropy is equal to zero, this would mean that mortality is concentrated at one age. The value of one would be another extreme value of entropy, in which case the intensity of mortality would be the same at every age (*Keyfitz – Caswell*, 2005: 80). This indicator can thus be used to characterise the overall shape of the survival curve and changes to it. Moreover, it is also easy to calculate this measure and the results are relatively clear.

Therefore, the IQR and entropy were both selected as indicators representing the total variability of ages at death relevant to the process of mortality compression and changes in the shape of the survival curve related to the process of rectangularisation. Again we will use the cohort life tables calculated for ages 60 and over.

Figure 7: **Development of the IQR of ages at death, the Czech Republic (upper graph) and France (lower graph), males, females, cohorts 1890–1910**





Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

At first, all the ages at death for each sex were divided into 4 quarters so that the IQR is the age range in which 50 % of deaths occur without the lowest and highest quarters. If the values of the IQR are decreasing, then the majority of deaths are concentrated in a narrower age interval surrounding the median of ages at death. This would be in accordance with the assumptions of the hypothesis of mortality compression.

As Figure 7 shows, in the Czech Republic the variability of ages at death had a decreasing tendency among both men and women in the oldest cohorts analysed. The variability began to increase again among cohorts born around the end of the 19th century. The temporal increase among Czech males in the 1900 cohort is a result of the special mortality pattern mentioned above (slightly higher mortality at ages up to ca 70 and lower mortality at ages above ca 75 than in preceding and subsequent cohorts). This exceptional situation is not apparent among females. The results confirm our assumptions that the variability of ages at death did not decrease, as the hypothesis of mortality compression would assume. This would mean that the process apparent in our cohorts does not correspond fully to the hypothesis as formulated by *Fries* (1980) and to all its assumed features.

For the French population a rapid increase in the variability of ages at death could be seen among males, as the graph of the distribution of deaths suggests (Figure 6). However, the situation of females is more interesting because the variability of ages at death increased slowly and with some simplification it could be said that the values remained nearly constant for all the cohorts in the analysis (especially the cohort born in 1901 and after). This confirms the conclusion that among French females the variability of ages at death did not change much, and rather the whole distribution shifted to higher ages (as is apparent in Figure 5). This is inconsistent with the assumptions of the hypothesis of rectangularisation or compression (where both these processes should occur simultaneously), so it could be said that the hypothesis was not proved, and nor was the existence of any theoretical limit of the lifespan.

Keyfitz and *Caswell* (2005: 81) claim that the indicator of entropy expresses the 'degree of concavity' of the survival curve, as deaths are still more concentrated around the mode. The values of the index of entropy (Table 5) are relatively high, especially for males, in our studied populations. This indicates a steep decrease in the survival curve above the age 60 for all the studied cohorts. From the values of entropy it is clear that the shape of the survival curve did not change much for Czech females or for French males in the studied cohorts (except the latest ones). A more concave curve with less uncertainty about ages at death is apparent only for French females. This development is usually taken as a positive one (*Keyfitz – Caswell*, 2005: 81). The opposite trend can be seen in the case of Czech males in the studied cohorts. The index of entropy increased what could be interpreted as the effect of negative mortality conditions during the second half of the 20th century. The index value for the latest cohorts of Czech males (above 0.49) represents a steeply and rapidly decreasing survival curve with no tendency towards rectangularisation.

Also of interest would be to compare period and cohort life expectancy. For this purpose we used cohort life expectancies at age 60 from the cohort life tables constructed above (cohorts 1890–1910). Those values were compared with period indicators published

Table 5: **Index of entropy, the Czech Republic and France, males, females, cohorts 1890–1910**

Cohort	Czech Republic		France	
	Males	Females	Males	Females
1890	0.463	0.387	0.487	0.401
1891	0.458	0.385	0.487	0.398
1892	0.463	0.381	0.487	0.398
1893	0.464	0.376	0.489	0.395
1894	0.462	0.378	0.489	0.393
1895	0.463	0.376	0.489	0.391
1896	0.467	0.374	0.491	0.387
1897	0.472	0.375	0.492	0.387
1898	0.470	0.375	0.493	0.384
1899	0.474	0.377	0.497	0.383
1900	0.487	0.375	0.495	0.379
1901	0.476	0.381	0.497	0.377
1902	0.484	0.380	0.497	0.377
1903	0.479	0.378	0.494	0.373
1904	0.482	0.382	0.494	0.370
1905	0.488	0.382	0.491	0.368
1906	0.489	0.383	0.491	0.364
1907	0.490	0.384	0.489	0.359
1908	0.494	0.386	0.486	0.357
1909	0.493	0.387	0.480	0.352
1910	0.491	0.385	0.476	0.349

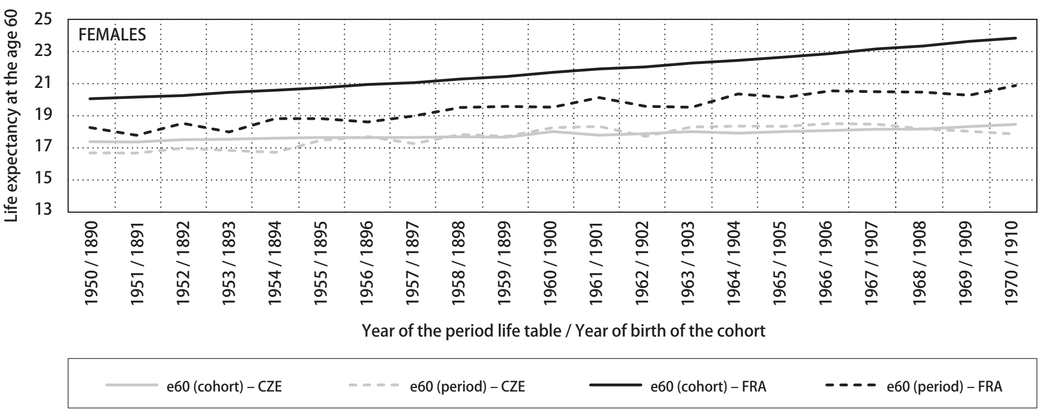
Source: Czech Statistical Office (Czech Republic); HMD (France); authors' calculation.

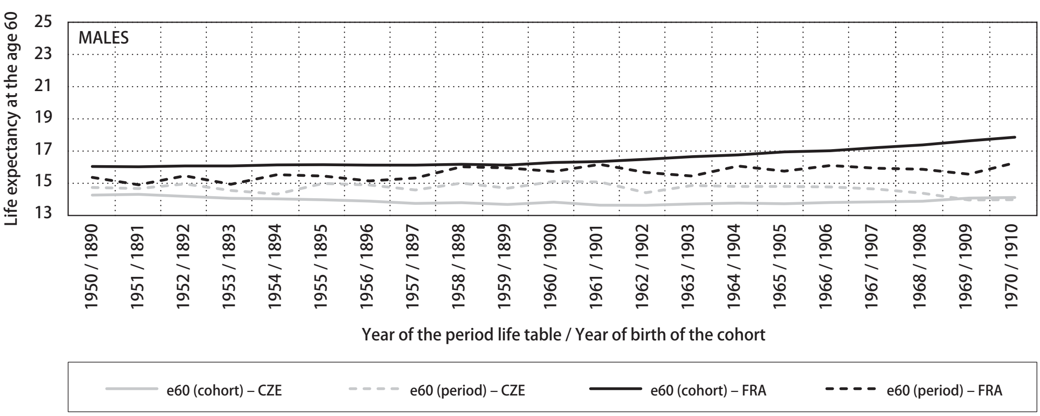
in the Human Mortality Database. Life expectancy at age 60 from our cohort life tables, for example, for the 1890 cohort, was compared with period life expectancy at age 60 from the period life tables for the year 1950. That means that those life expectancies are comparable.

As we can see (Figure 8), the two life expectancies are almost identical for females in the Czech Republic; this is owing to the relatively stable development of mortality for those cohorts. Only for the latest cohorts do we see cohort mortality start to surpass period life expectancy. The reason for this is the more recent improvement of mortality at higher ages among the youngest cohorts. For females in France the situation is completely different. There cohort life expectancy at age 60 is approximately 2 years higher than period life expectancy. This is the result of the mortality improvements that occurred during the second half of the 20th century.

By contrast, for Czech males the period indicator was higher than the cohort indicator in almost all the generations analysed. From this it can be concluded that in a situation of increasing mortality cohort life expectancy has the tendency to be lower than period life expectancy and vice versa. This fact could be important above all in those situations where period indicators are used for estimates pertaining to the future of the cohorts. This conclusion is al-

Figure 8: **Comparison of the period and cohort life expectancy at the exact age 60, the Czech Republic, France, females (upper graph), males (lower graph)**





Source: HMD (period measure); authors' calculation (cohort measure).

so supported by the results for French males. The cohort measure is significantly higher than the period measure because of the decrease in mortality and the rising variability of ages at death during the latest years analysed (Figures 7 and 8).

CONCLUSION

This article presented a basic comparison of the period and cohort perspectives of demographic analysis. The populations of the Czech Republic and France were chosen for this comparison. We focused on adult mortality, which was defined as mortality at ages 60 and over. In the theoretical part of the text several concepts dealing with mortality development at those ages were mentioned, and the hypothesis of the rectangularisation of the survival curve or mortality compression was chosen as the basis for the analysis. This hypothesis asserts that changes in the survival curve cause the curve to assume an increasingly rectangular shape as the variability of ages at death decreases around the mode (*Fries*, 1980). Empirical confirmation of this hypothesis cannot be taken as a direct proof of the existence of some fixed limit to human life, however it could suggest that there may be a way of using this type of analysis to find such a limit.

The focus on the highest ages was not the only reason why only ages 60 and over were considered in the analysis. The second reason was the availability of the necessary data. The time series of cohort data, which could only be taken from one source, is shorter in the Czech Republic than in France. So we decided to analyse in both countries cohorts born in 1890–1910, who began to reach the age of 60 in 1950 and after and can now be considered to be extinct. These cohorts were also studied with respect to the period effect observable during the second half of the 20th century.

The basic analysis of the cohort life tables proved that especially in France mortality improvements are observable not only in the period perspective but across all the cohorts analysed. However, the analysis also revealed that the variability of ages at death increased rapidly, which contradicts the assumptions of the hypothesis as it was originally formulated. Almost the same development was observed for Czech females, but for Czech males the development and pattern of cohort mortality was strongly influenced by unfavourable period changes (particularly during the 1960s, the 1970s and partly also the 1980s).

The indicator of entropy was used to perform a quantitative analysis of the shape of the survival curve. The decreasing values of this indicator observed among French cohorts (for males only among the youngest cohorts) express a positive change in the shape of the survival curve at the highest ages, where the curve becomes more concave. These results combined with the increasing variability of ages at death for males (indicated by increasing IQR values) and the relatively stable variability of the IQR for French females allow us to conclude that the hypothesis about the simultaneous rectangularisation and mortality compression does not hold true for the French cohorts. The described development instead involved mortality shifting, where the whole survival curve is more or less shifted to higher ages with nearly unchanged (or even higher) variability of ages at death.

The above analysis showed that mortality development in the Czech Republic (represented by the same range of cohorts) was not as positive as in France. For Czech females the shape of the survival curve and the distribution of deaths remained almost unchanged. The IQR and entropy indicators also showed this. According to this, mortality among Czech females could be regarded as having stagnated. For Czech males the situation was even worse. The index of entropy revealed an even more steeply decreasing survival curve than among females. At the same time, the variability of ages at death increased. These observations indicate a process of derectangularisation or expansion of mortality, which means that the hypothesis did not prove true for the Czech population either. However, further analysis of this development would be required in order to determine whether future cohort mortality development will be more like that in France (mortality shifting) or will conform more to the assumptions of the hypothesis of mortality compression and rectangularisation. From the cohorts analysed in this paper, the assumptions of *Fries* (1980) or about any limit of the human lifespan were not proved for either of the populations studied, though the development in each of them differed significantly.

All the analyses above were based on cohort life tables constructed only for ages 60 and over. The construction of complete cohort life tables is still a challenge that Czech demography is now faced with. It is highly data-demanding. But this analysis proved that conclusions based on cohort analysis may be significantly different from conclusions based on period data. This could be important for future plans and estimates, for example, in connection with social or pension reforms.

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Appendix 1 | Countries with constructed and published cohort life tables

Country	Notes	Citation of a publication or source
Canada	Generations 1801–1991	Bourbeau, R. – Légaré, J. – Émond, V. (2004)
New Zealand	Generations 1876–1935	Statistics New Zeland (2006)
United Kingdom	Based on historical mortality rates from 1981 to 2008 and on projections	http://www.statistics.gov.uk/downloads/theme_population/Interim_Life/period_cohort_tables_index08.pdf
Poland	10-year periods from 1801 to 1950	Piasecki E. (1984)
USA	For births in decennial years 1900 through 2000	Bell, F. C. – Miller, M. L.
Germany	Generations 1903–1993	Bomsdorf, E. (1993)
England and Wales	Generations 1841–1960	Case, R. A. M., et al. (1962)
Australia		Lancaster, H. O. (1959), Young, C. M. (1969)
Belgium		Veys, D. (1981)
France		Delaporte, P. (1941), Vallin, J. (1973)
Netherlands	Generations 1850–1989	Tas, R. F. J. (1991), Van Poppel, F. – Tabeau, E. – Willekens, F. (1996)
Sweden	Generations 1885/89–1940/44	Schoen, R. – Urton, W. L. (1979), Bolander, A.-M. (1970)
United States	Generations since 1840	Jacobson, P. H. (1964)
Bulgaria, Russia	Life tables for various life course events, constructed for four real cohorts, 1940–44, 1950–54, 1960–64 and 1970–74	Philipov, D. – Jasilioniene, A. (2008)

Appendix 2 | Constructed cohort life tables available in the Human Mortality Database

Country	Notes
Denmark	Generations 1835–1917
Finland	Generations 1878–1918
France	Generations 1816–1916
Iceland	Generations 1838–1917
Italy	Generations 1872–1916
Netherlands	Generations 1850–1917
Norway	Generations 1846–1917
Sweden	Generations 1751–1917
Switzerland	Generations 1876–1916

Source: Human Mortality Database (www.mortality.org), cited in March 2011.

REDAKČNÍ SDĚLENÍ A VÝZVA K ZASLÁNÍ PŘÍSPĚVKŮ

Vážení čtenáři,

Redakční rada rozhodla, že v 55. ročníku revue Demografie (2013) bude číslo 3 připraveno jako monotematické. Jako zaměření tohoto čísla bylo zvoleno téma „Plánování rodičovství“. Žádáme čtenáře a přispěvatele Demografie o nabídku příspěvků. Jako dílčí témata bude redakce preferovat analýzy výstupů demografické statistiky, výběrových šetření plodnosti, sociologických průzkumů a anket, informace z workshopů a konferencí zaměřených k tomuto tématu. Zájem bude zejména upřen na změny postojů obyvatelstva k plánování rodičovství a preferencím reprodukčního modelu rodiny v posledních dvou desetiletích.

Nabídky příspěvků a své další náměty k monotematickému číslu Demografie zasílejte, prosíme, redakci elektronicky do 31. 5. 2013 na adresu redakce@czso.cz. Monotematické číslo vyjde v 1. polovině září 2013. Akceptovány budou příspěvky v českém a anglickém jazyce s tím, že anglicky psané příspěvky vybrané k publikaci budou otištěny v angličtině. Autorům předběžně vybraných příspěvků budou zaslány podrobné dispozice.

Marie Průšová
výkonná redaktorka