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THE EVOLUTION OF LONGEVITY: EVIDENCE FROM CANADA

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ABSTRACT

We find a steep earnings-longevity gradient using fifty years of administrative data from Canada, with men in the top ventile of earnings living eight years (11 percent) longer than those in the bottom ventile. For women, the difference is 3.6 years. Unlike the United States, this longevity gradient in Canada has shifted uniformly through time, with approximately equal gains across the earnings distribution. We compare our results using cross-sectional and cohort-based methods, finding similar trends but a steeper gradient when using cohorts. For middle-aged men, we find a cessation of mortality improvements in recent years, comparable to changes observed in the United States. Changes in income do not explain cross-time or cross-country differences.

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1 Introduction

Concerns about inequality of economic outcomes have dominated the economic and political debates of the 21st century. A fundamental dimension of inequality is longevity, which has come more sharply into focus with the findings of Case and Deaton (2015, 2017) showing increases in mortality among white non-Hispanic middle-age males. The causal nature of the relationship between socio-economic status and longevity is a matter of ongoing debate.[1] However, the distribution of longevity—whatever the cause—constitutes a central facet of the distribution of wellbeing in a society. Moreover, changes in the distribution of longevity have far-reaching policy implications for Social Security and other public programs, as explored recently by National Academies of Sciences, Engineering, and Medicine (2015).

The urgency of the debate in the U.S. arises from the increase in the longevity gap between higher and lower earners.[2] There are a number of potential sources for the increasing longevity gap, ranging from direct effects of income to indirect effects of income inequality through education, health behaviors, health insurance, or health care. Some of these factors manifest particularly in the United States among high-income countries (such as health insurance coverage or more extreme income inequality), while others (such as education) are fairly comparable to other high-income countries. This suggests that examining the evolution of the longevity gradient in other countries can inform discussion of the sources of the increasing longevity gradient in the United States.

In this paper, we address the evolution of longevity gradients by studying the long-run relationship between earnings and longevity in Canadian administrative public pension data. We examine survival to older ages across quantiles defined by a measure of individual lifetime earnings, looking at changes across thirty years of birth cohorts and fifty years of observed mortality. Our work builds on a recent contribution by Chetty et al. (2016), which examines similar questions of income and longevity using cross-sectional projections based on a sample of Americans between the years 2001 and 2014. We contribute through analyzing cohort rather than cross-sectional longevity, made possible because our data spans fifty years. Using cohort data not only affords a thirty-year horizon on changes in longevity, but also means we need not rely as heavily on projections to form our survival rates and expected lifespans. Our research here includes a comparison of life

[1] See Cutler et al. (2006) for a discussion of the causal relationship between socio-economic status and mortality both across and within countries.

[2] The literature is reviewed in the next section, but a definitive recent documentation of the unequal evolution of the mortality gradient over time can be found in National Academies of Sciences, Engineering, and Medicine (2015).

expectancies under cohort-based and cross-sectional methodologies. Moreover, we can compare the impact of measuring average earnings over short (one year) to longer (ten year) periods to observe the sensitivity of longevity gradients to how income is measured.

We have two major findings. First, we document substantial differences in life expectancy across the earnings distribution in Canada. Over the time period of our sample, men in the top five percent of the earnings distribution lived eight years longer than those in the bottom five percent after age 50, a difference of around 11 percent of a lifespan. This contrasts to a difference of 12 years between top and bottom ventiles found by Chetty et al. (2016) for the U.S. from age 40. Second, longevity in Canada has shifted almost uniformly for males across the earnings distribution, with very similar gains at the bottom and top. This finding is in stark contrast to the United States where longevity gains have been much larger at the top of the income distribution.

In addition, we also document that mortality improvements for 50–60 year old Canadian men stopped for recent cohorts, but we see no reversal as uncovered for the United States for non-Hispanic white males by Case and Deaton (2015). We find that the uniform shift across the earnings distribution persists when we apply a cross-sectional methodology to our data. Finally, we show that earnings differences across cohorts and between Canada and the U.S. do not explain much of the observed gaps.

We begin by discussing related research to put our approach and results in context. We then describe our dataset and empirical methods. Next is our main results, followed by extensions that facilitate comparison to recent U.S. research. We conclude with a discussion of the possible explanations and implications of our findings.

2 Related Research

The seminal empirical work of Kitagawa and Hauser (1973) studied socio-economic status and mortality by merging death records onto the 1960 U.S. Census, finding lower socio-economic status was correlated with higher mortality. Many subsequent researchers have used a similar strategy, including Duleep (1989) and Pappas et al. (1993), among others. Recent work matching survey data with Social Security records has updated these findings and provided longer-run perspectives. National Academies of Sciences, Engineering, and Medicine (2015) and Auerbach et al. (2017) use the Health and Retirement Study, Meara et al. (2008) uses the Current Population Survey, while

Cristia (2007), Attanasio and Hoynes (2000), and Bosworth et al. (2016) use the Survey of Income Program and Participation. Currie and Schwandt (2016) compares mortality inequality by ranking counties by various measures of socio-economic status and comparing mortality rates. They find substantial improvements through time in the U.S. at younger ages driven by diminishing gaps with more disadvantaged children.

In Canada, Mustard et al. (2013) look at mortality after unemployment in Canada, using a match of 1991 census records with mortality files. Similarly, Mustard et al. (1997) merge 1986 census records with mortality data from the province of Manitoba. Boisclair et al. (2015) perform longevity simulations based on data from the National Population Health Survey, exploring the implications of longevity changes for public pension plans. Finally, Baker et al. (2017) applies the Currie and Schwandt (2016) ranking methodology to Canada, finding decreases in socio-economic gradients at younger ages.

All of this research using surveys carries an advantage: one can look at varied dimensions of socio-economic status; including income, race, marital status, and education. However, the smaller sample sizes and compressed time coverage of surveys limits the ability of researchers to address fundamental longer-run questions.

Administrative data, while lacking in covariates, often affords larger sample sizes and may permit longer-run analysis. In Canada, Wolfson et al. (1993) used Canada Pension Plan administrative data, studying earnings gradients of mortality for early cohorts of Canada Pension Plan contributors. They find lower mortality rates between ages 65 to 74 for those in the highest earnings quintile. While informative, the analysis was necessarily restricted to just 24 years because the Canada Pension Plan only started covering earnings in 1966. This limited both the cross-cohort comparisons and the analysis of older-age mortality. Office of the Chief Actuary (2015) also use CPP administrative data, looking at mortality patterns of those over age 65 by CPP benefit levels. Since Canada Pension Plan benefits don't cover earnings in the top half of the earnings distribution, this study is limited in its scope to study differences across the whole earnings distribution. Recent work by Ahmadi and Brown (2018) uses a large cross-section of administrative records from firm-sponsored pension plans to characterize the relationship between mortality and observable characteristics, including disability, occupation, and pre-retirement earnings. Using a limited time period (2012-2014) and such a selective sample of firms and plan participants, limits their ability to inform broader public policies.

In the United States, Waldron (2007) uses Social Security records spanning 1912 to 1941, finding improvements in mortality were concentrated in the top half of the lifetime earnings distribution. Duggan et al. (2008) also uses Social Security administrative records covering the 1900 to 1942 birth cohorts, finding only a small 2-3 year difference in the age of death between the 10th and 90th percentile of lifetime earnings. Most recently, Chetty et al. (2016) merge income tax data to Social Security Administration death records, using the universe of individuals with a Social Security Number between the years 1999 and 2014. Family income two years prior is used to sort individuals into quantile bins and observed cross-sectional mortality rates are projected to fill in older ages, allowing the computation of expected lifespans conditional on attaining age 40. They find a strong gradient of life expectancy with income percentile, and increases in life expectancy through the 2001–2014 period of observation that strongly favor higher earners.

Our paper contributes to this literature in several ways. First, our administrative data source affords an extraordinary time-span of data and sample sizes, and also permits the use of cohort rather than cross-sectional analysis. We are able to use our data to check on the assumptions used by other recent papers in this literature such as the averaging period used to gauge lifetime earnings and also compare cohort to cross-sectional methods. In addition, by comparing the results on the evolution of longevity in Canada to those in the United States, we can gain insight into what may be driving the steepening mortality gradients in the U.S.

3 Data

We employ administrative records from the Canada Pension Plan (CPP), Canada's earnings-related public pension plan covering Canadians outside Quebec.[3] The data provide precise and detailed administrative information such as birth date, death date, benefit-claiming date, and annual earnings. We do not observe personal characteristics such as education, race, place of residence, or immigrant status; and we cannot link across spouses. We draw a sample of over 11 million individuals born between 1916 and 1955, representing the records of all CPP contributors born in this period. We observe these individuals between the years 1966 (the inaugural year of the CPP) and 2015.[4] There are different databases for earnings and for benefits. When one applies to take up a Canada Pension Plan benefit a record in the benefits file is originated based on the information in

[3]We make use of an existing administrative file known as the "OCA" file, which is prepared for the periodic statutory review of the Canada Pension Plan by the Office of the Chief Actuary of Canada.

[4]The initial sample and sample selection discussed in this section is summarized in Appendix A.1.

the earnings file.[5] We describe each of these databases in turn.

The CPP collects earnings information for everyone who has worked in Canada (outside the province of Quebec) starting at age 18. CPP contributions on earnings must be made until age 65.[6] These earnings are reported by employers to the tax authority on behalf of the employees. For the self-employed, earnings must be reported on the annual income tax filing. The earnings database includes lifetime earnings (starting in 1966 or age 18) for anyone who earned in Canada (outside Quebec) at least once. If someone subsequently moved to Quebec or out of Canada entirely, he or she would still appear in our earnings database. Until 1971, earnings were topcoded to four digits for each employer; and from 1972 onward only five digits of annual earnings are available for each employer. Moreover, for some years reported earnings appear to be top-coded at the pensionable earnings cap for a subset of the sample. For those who are topcoded, we impute earnings above the cap using individual information on earnings growth rates in neighboring uncapped years. We tested the impact of the imputations on our mortality gradient measures, but found our results insensitive to the imputations.[7] Further details and assessment of these imputations are in Appendix B.1. The earnings database also includes date of death, including from those who died before (or without ever) claiming benefits. We address the issue of missing data for this death information below.

The CPP benefits database includes information on CPP benefits, including benefit type, the effective date the benefit began, date of birth, and any reported date of death. Those who claimed benefits under Quebec's parallel plan are not included in this benefits database; nor are those who never file a claim for benefits. Non-claiming could arise from not being aware of an entitlement, a decision that a small entitlement is not worth the application effort, or because the person has left Canada. We explore the implications of never claiming in Appendix B.2.

Our main focus is the relationship between a measure of lifetime earnings and survival. To measure lifetime earnings, we took the sum of reported employment and self-employment earnings and construct an inflation-adjusted average of earnings between the ages 45 to 49 (discussed more below). We then condition our sample on survival to age 50 by including only those surviving to

[5]There is also a separate database for disability benefits. We only use the disability database here to collect death records in case the death was missed in the other databases.

[6]Since 2012, CPP recipients who keep working and make contributions after age 65 receive a special post-retirement benefit.

[7]This insensitivity may result from the limited degree of earnings mobility among those in the upper end of the earnings distribution at ages 45 to 49. Being a high earner is fairly persistent by that point in one's career, so the top coding doesn't strongly reshuffle an individual's quantile ranking.

at least December 31st of the year they turn 50. For survival, we code a binary variable indicating survival to a given age. In all cases, we use age on December 31st to measure age. Because we need to observe five years of earnings, our earliest potential year of birth cohort is 1921, but for reasons described below we make use of only those in the 1923 and onward birth cohorts.

We imposed several additional sample conditions which are described briefly here but documented in Appendix A. We remove a small number of individuals with inconsistency in birth dates and sex across the two databases. To ensure consistency of the sample across our earnings and benefits databases, we remove from the earnings database those who are earning in Quebec in their final observed year, since they are likely to claim Quebec Pension Plan benefits instead of CPP benefits, and therefore not be seen by us in the benefits database in later years. In addition, some of those in the earnings database never appear in the benefits database and are never coded as dead in the earnings database, which creates the appearance of excess survivorship affecting some particular areas of our sample. The analysis in Appendix B.2 demonstrates that this manifests most strongly for those that appear to be the lowest earners in the earliest cohorts. To help us overcome this challenge, we impose the condition that at least four of the five years between age 45-49 have non-zero earnings. This condition removes more women then men, especially among our oldest cohorts. Appendix A.4 provides sensitivity analyses for these decisions. We also discard for our analysis the cohorts born before 1923 where the excess survivorship problem was most acute.

Table 1: Sample Counts

	Males			Females		
Year of birth	Sample	Population	Percent	Sample	Population	Percent
1921-1929	741,890	1,100,725	67.4%	364,490	1,118,076	32.6%
1930-1939	853,380	1,281,570	66.6%	546,150	1,258,953	43.4%
1940-1949	1,116,390	1,749,114	63.8%	934,025	1,743,832	53.6%
1950-1956	1,028,310	1,614,514	63.7%	938,440	1,637,087	57.3%
Total	3,739,970	5,745,923	65.1%	2,783,105	5,757,948	48.3%

Note: Data are from the OCA administrative file of the Canada Pension Plan. Numbers rounded to the nearest 5 to conform with disclosure requirements. We report the final counts from our sample, from the original population, and the percentage of the population in our sample.

The final sample contains 3.7 million men and 2.8 million women. In Table 1 we show the final sample count for males and females by decade of birth. The table also shows the population count at age 50, and the percentage of the total population appearing in our sample. The difference between our sample and the population is primarily accounted for by those who did not ever earn (and therefore were not in our sample at all) and those who earned but did not attain the four years of earnings required by our sample selection criteria. As reported in Appendix A.1, about 26 percent of our males did not satisfy the required earnings criteria, and 38 percent of females. Our sample, however, is still highly representative of the population. As a check on this, we constructed age-specific annual mortality rates to compare to national aggregate mortality rates. The correlation for males is 0.999 and for females is 0.996.[8] More details can be found in Appendix A.2.

4 Empirical Approach

Our data span 50 years, allowing us to construct cohort-based measures of longevity. In contrast, standard longevity measures use observed cross-sectional data to make longevity calculations by imposing the strong assumption of stable mortality rates across ages observed in any given year. For much of our data, we can simply calculate actual cohort longevity measures without assumption. To fill in the gaps at older ages we do not observe, we use standard projection methods based on Gompertz Law; but even there we do not need to make cross-cohort assumptions.

To begin this section, we describe our approach to forming a measure of lifetime earnings. Following that, we explain our methods for measurement of survival and projections for longevity.

4.1 Earnings and Sorting

We proxy for lifetime earnings using inflation-adjusted average earnings between the ages of 45 and 49. Appendix C.1 provides sensitivity analysis on this five-year window, showing little difference in survival probabilities when we sort our sample using a one-year, five-year, or ten-year window for average earnings. Separately for males and females for each year of birth, we sort the sample into quantile bins. Most of our analysis uses ventiles (20 bins; numbered from 1 at the lowest to 20 at the highest) while for other analysis we use percentiles (numbered from 1 to 100). Because of sample size considerations, we pool together three years of birth for some of the analysis, while at other times we group by decade.[9]

[8] Chetty et al. (2016, p. E2) report a correlation of 0.98 for the analogous test in their data.

[9] In section 6.3 we examine how our results change when we use alternative sorts based on pooled data across cohorts or thresholds derived from the U.S. earnings distribution.

4.2 Survival rates

We condition our sample on survival to age 50, giving us an initial population for each year of birth yob and sex m of $P^{50}_{m,yob}$. We observe deaths at each age a from 51 to 100, $D^{a}_{m,yob}$. So, we define cohort and sex-specific survival rates $S^{50,a}_{m,yob}$ from age 50 to age a as:

$$S^{50,a}_{m,yob} = 1 - \frac{\sum_{i=51}^{a} D^{i}_{m,yob}}{P^{50}_{m,yob}}, \forall a \in \{51, \ldots, 100\}. \tag{1}$$

We can use these survival rates to calculate the average length of lives; which could also be interpreted as a cohort-specific life expectancy from the viewpoint of age 50. We do so by summing survival rates at ages after age 50, allowing us to form a cohort-specific measure of average life after age 50 for any age range up to a.

$$L^{50,a}_{m,yob} = \sum_{i=51}^{a} S^{i}_{m,yob}, \forall a \in \{51, \ldots, 100\}. \tag{2}$$

In our analysis we make use of expected life in intervals between ages 51 to 100. We also do these calculations separately for each quantile for each sex and cohort.

4.3 Gompertz projections

With data from 1966 to 2015, we can observe survival from age 50 up to age 90 for the 1925 birth cohort, but only up to age 60 for the 1955 birth cohort. We desire to project expected lifespans up to age 100, $L^{50,100}_{m,yob}$ for each sex and cohort. To fill in missing survival rates we make projections based on Gompertz Law (see Gompertz, 1825). Gompertz Law posits that the relationship between age and mortality is log-linear. Recent evidence (see Gavrilov and Gavrilova, 2011; Gavrilova and Gavrilov, 2014) shows that the relationship holds very well at ages as old as 90.[10]

We form age-specific mortality rates $M^{a}_{m,yob}$ for each birth cohort and sex using our data on deaths $D^{a}_{m,yob}$, and population $P^{a}_{m,yob}$:

$$M^{a}_{m,yob} = \frac{D^{a}_{m,yob}}{P^{a}_{m,yob}}. \tag{3}$$

[10] In particular, with annual data the bias from uneven distribution of ages across years does not arise before age 90 (Gavrilov and Gavrilova, 2011, p. 438). After age 90 this bias grows, leading Gompertz projections with annual data to underpredict mortality.

Using the available data, we run ordinary least squares regressions of log mortality on age of the form:

$$\ln M^{a}_{m,yob} = \beta_0 + \beta_1 a + \epsilon_{a,m,yob}. \tag{4}$$

Using this model, we project mortality as $\mathbb{E}(M^{a}_{m,yob}|a) = \widehat{M^{a}_{m,yob}} = e^{\beta_0+\beta_1\times a}$. We then form projected survival as:

$$\widehat{S^{50,a}_{m,yob}} = S^{50,a-1}_{m,yob} \times (1 - \widehat{M^{a}_{m,yob}}). \tag{5}$$

Again, this is done separately for each quantile.

To form our complete block of survival rates (age 51–100 for all cohorts), we follow Chetty et al. (2016) and splice together longevity data over three distinct age ranges. First, we use actual data when available up to age 75 (for cohorts born 1940 and earlier) or the last age available (cohorts born after 1940). Next, we use Gompertz projections based on data from age 50-75 to form survival rates for ages up to 89. Third, we use population longevity data for ages 90 plus.[11] We evaluate the fit of the Gompertz projections in Appendix B.3. The population longevity data over age 90 helps to ensure sample survival approaches population survival at these oldest ages where the Gompertz projections may hold less well.

5 Main Results

The presentation of results begins with basic survival rates by sex, cohort, and quantile. We then characterize the changes in projected life expectancy across cohorts and earnings quantiles.

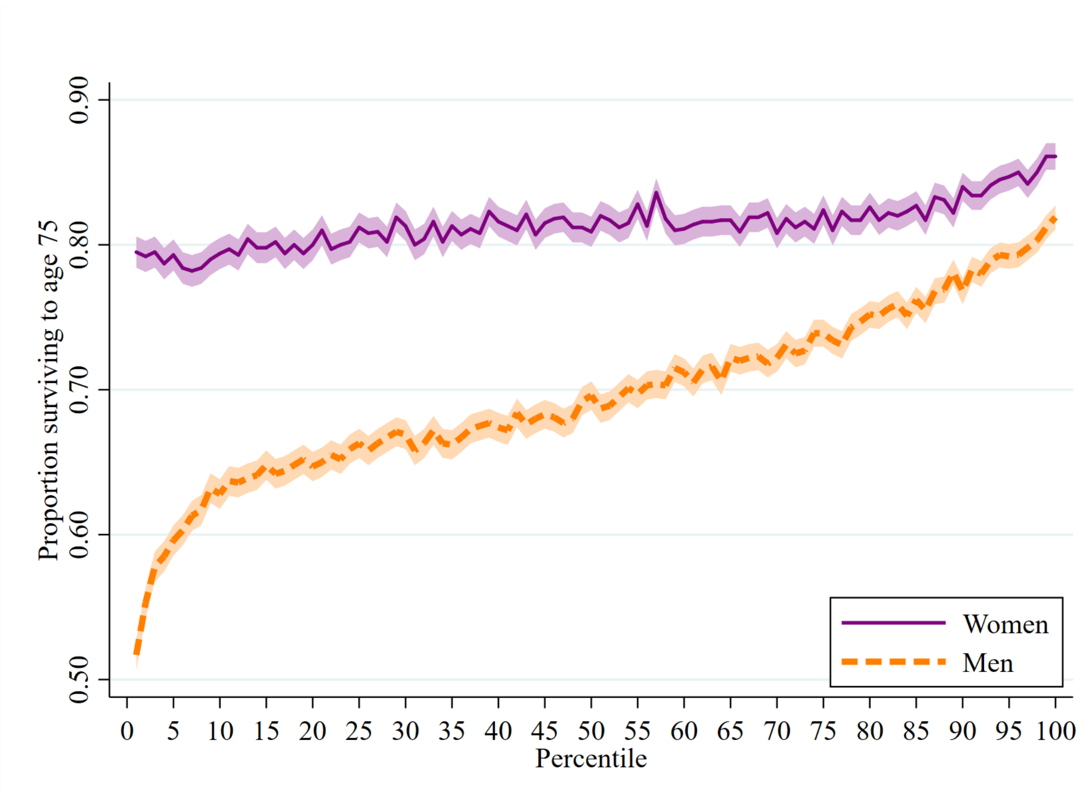
5.1 Survival rates by quantile

We focus first on survival rates since they constitute the most basic component of our data and emphasize the advantages of our cohort-based approach. In the analysis that follows, these survival rates will be aggregated and projected to form life expectancies. But here, to begin, we examine survival rates to age 75 by percentile of age 45-49 earnings for those born in the 1930s and who

[11] We use cross-sectional mortality rates for ages 90+ taken from 2010. The source is the Canadian Human Mortality Database (2016).

were alive at age 50. For these cohorts, we can use actual survival rates observed in the data without Gompertz projections. There are separate lines for women and for men, with a 95 percent confidence interval indicated for each line by shading.

Figure 1: Survival to age 75 by earnings percentile



Note: Data are from the OCA administrative file of the Canada Pension Plan. Earnings percentiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Sample includes only those who survived to age 50. The shaded areas indicate the bounds of the 95 percent confidence intervals.

Figure 1 shows three clear results.First, for men there is a strong survival gradient with earnings with a milder gradient for women. This parallels the findings of Chetty et al. (2016), although our analysis is based on a woman's own earnings, while Chetty et al. (2016) used a family income measure.[12] In our sample, the milder slope for women is therefore driven not only by the higher underlying survival rates of women generally, but also by our sample selection criteria that leads to the inclusion of only those women with earned income. Second, as found by Waldron (2013) and Chetty et al. (2016), survival for men at the bottom percentiles falls off sharply, with a difference

[12] Appendix figure 9c in Chetty et al. (2016) shows very little sensitivity of their results to family versus individual incomes for men or women.

between the 1st and 10th percentile of 11 percentage points for men. Third, the almost-linear consistency of the gradient over much of the earnings distribution provides further evidence against the "hardship threshold" hypothesis studied and rejected in Wolfson et al. (1993) and Waldron (2013). There are continued gains in survivorship as earnings increases. Between the 10th and 100th percentile, the rise in age 75 survival is close to linear, going from 63 percent to 82 percent. So, a man at the 90th percentile of lifetime earnings has about 25 percent greater chance of living to age 75 than does a man at the 10th percentile of earnings.

We now proceed to analysis of longevity gradients over time to examine how life expectancy has shifted across cohorts.

5.2 Life expectancies and changes in longevity

We form life expectancies for each gender, quantile, and cohort using observed and projected survival rates. We project mortality and survival rates in the age range up to 89 using the actual data when available and Gompertz Law projections for ages with no survival rate available. We then add in population mortality from age 90 in order to complete an age 51–age 100 block of survival rates for each gender, quantile, and cohort. Finally, we aggregate these survival rates into life expectancies. We report the number of expected years of life after age 50.

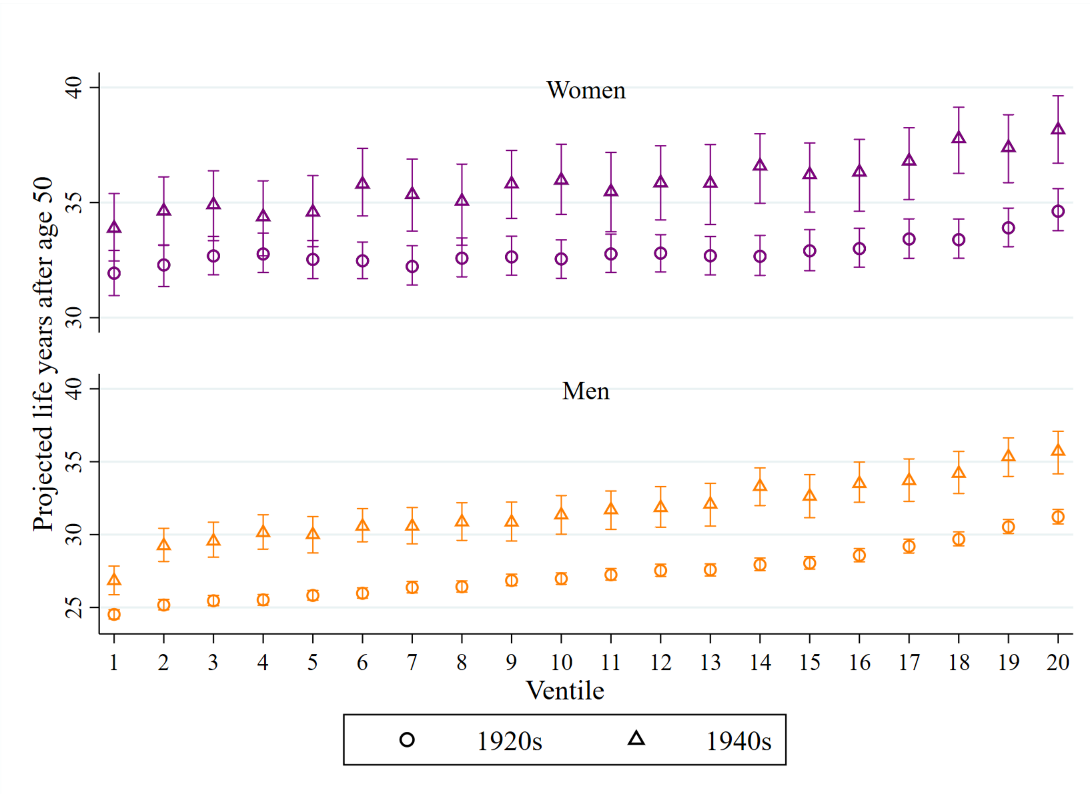
The variability of our life expectancy projections changes across cohorts, driven by two factors. We have more observations for later cohorts, which pushes the variability down. But, our Gompertz regressions can only use data up to age 60 for a birth in 1955, so the short span of survivor data for more recent cohorts leads to larger variability in the projections. We have the full range over ages 51–75 for the Gompertz regressions for all cohorts from 1940 and earlier. In the discussion of the results, we therefore make use of simulated confidence intervals for inferences about our life expectancy projections.[13]

We begin with an analysis of those born in the 1940s, and then compare to those born in the 1920s.[14] We extend the analysis to the 1950s in a separate analysis below. Figure 2 displays the projected years of life after age 50 by ventile, separately for women and for men. Each point has a simulated 95 percent confidence interval indicated. The figure reveals important results for both

[13]To form the confidence intervals, we do 1000 simulations of our life expectancy projection. We measure the observed sample mean and standard deviation for each sex, cohort, quantile, and age cell. We use these observed sample moments to make draws on mortality rates based on a normal distribution and form our confidence intervals using the 2.5th and 97.5th percentiles of the resulting distribution.

[14]Our 1920s data incorporates births between 1923 and 1929 while for the 1940s we have 1940–1949.

Figure 2: Life expectancy from age 50 by ventile and cohort



Note: Data are from the OCA administrative file of the Canada Pension Plan. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Sample includes only those who survived to age 50. The point estimate is indicated by the marker; the lines show the extent of the simulated 95 percent confidence interval.

the slope of the life expectancy-earnings gradient and how it has changed through time.

The life expectancies of both women and men exhibit a gradient in Figure 2. For women, the top-to-bottom ventile gradient of life expectancy for those born in the 1940s is 4.3 years while for men it is 8.9 years. Both of these gradients are statistically significant at the 95 percent confidence level. Living 8.9 years longer is an increase of one third in the post-age 50 lifespan compared to the 26.8 years of life for men in the first ventile, and an 11.6 percent increase in the overall life expectancy compared to the base of 76.8 years for first-ventile men. For women, 4.3 years is a 13 percent increase in life after age 50, and a 5 percent overall increase in lifespan.

We now turn to the shifts in this earnings-longevity gradient through time. Comparing the 1920s to the 1940s in Figure 2, the shift in life expectancies is mostly uniform across ventiles for women and for men. The shift for women in the bottom five ventiles (and the 11th) is not statistically significant, but attains significance at the 95 percent level at other ventiles. For men, the shift between the 1920s and 1940s in Figure 2 is significant for all ventiles, and with an average increase of 4.4 years.[15]

We can extend the analysis to the 1950s, although the more limited window of observable survival rates means that our life expectancy projections become more variable. For this reason, we aggregate to quintiles to make the comparisons of the 1920s to the 1950s. Using quintiles also facilitates comparisons with the key findings of National Academies of Sciences, Engineering, and Medicine (2015). We present the analysis across all decades and quintiles in Table 2.

Looking across the top panels of Table 2 horizontally, the top-to-bottom quintile gradient for Canadian women grows through time, from 1.3 years in the 1920s to 3.2 years in the 1950s– although it is not clear how much of this change is driven by different selection into the workforce by women across cohorts. Canadian men, on the other hand, exhibit a fairly stable gradient between 4.9 years and 5.8 years across the four decades.

Comparing the 1950s to the 1920s vertically in Table 2 reveals the growth in longevity across cohorts. For women, there is no clear pattern across quintiles, with the largest gain in the 3rd quintile at 4.9 years and the other quintiles showing smaller gains. Again, differential selection across cohorts makes these comparisons less easy to interpret for women. For men, there are very stable gains across the quintiles, ranging from 4.3 years of projected extra life in the first quintile to 5.1 years in the fifth quintile.

[15] The shift is 2.3 years for the first ventile, much lower than the other ventiles. In part this reflects the permanent survivor phenomenon we explore in Appendix B.2 that affects particularly 1920s cohorts in the lowest earnings ventiles.

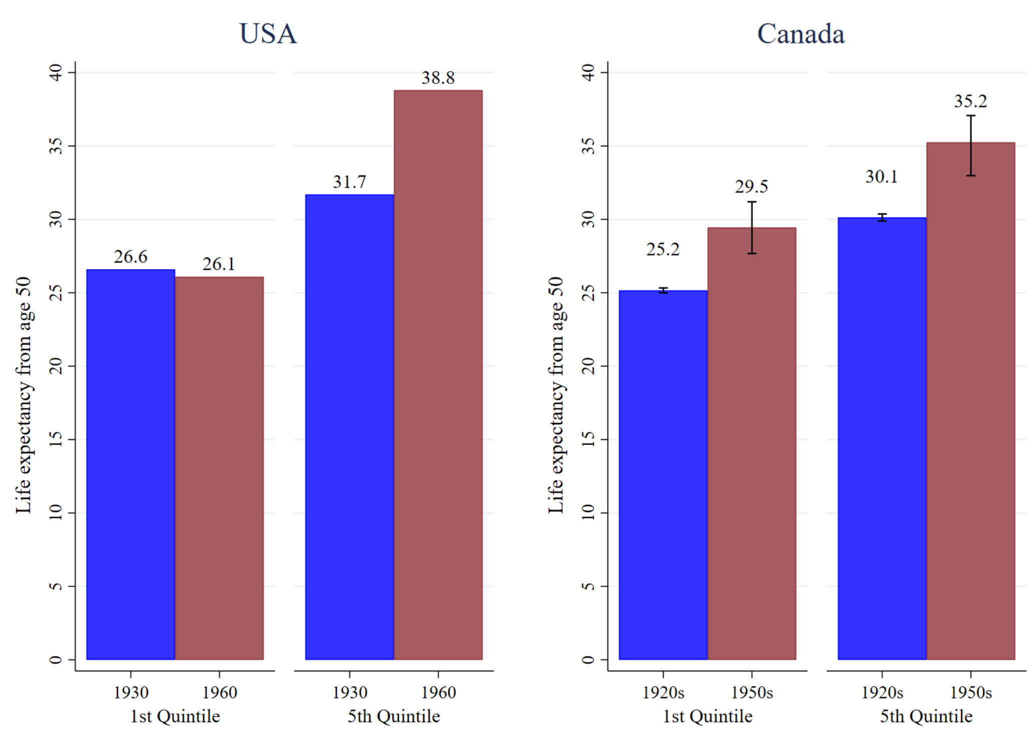
Table 2: Life expectancy from age 50 by quintile and cohort

Birth Cohort	Quintile 1	2	3	4	5
			Canada-Women		
1920s	32.5 (32.1,32.9)	32.5 (32.1,32.9)	32.7 (32.3,33.1)	32.8 (32.4,33.2)	33.8 (33.4,34.2)
1930s	33.4 (33.1,33.8)	34.1 (33.8,34.5)	34.3 (33.9,34.6)	34.3 (34.0,34.7)	35.3 (35.0,35.7)
1940s	34.4 (33.6,35.2)	35.2 (34.5,36.0)	35.8 (35.0,36.6)	36.3 (35.4,37.0)	37.5 (36.7,38.2)
1950s	34.0 (31.7,36.2)	36.5 (34.2,38.3)	37.6 (35.4,39.1)	36.0 (33.3,38.0)	37.2 (34.7,39.2)
			Canada-Men		
1920s	25.2 (25.0,25.3)	26.1 (25.9,26.4	27.2 (27.0,27.4)	28.0 (27.8,28.3)	30.1 (29.9,30.4)
1930s	27.3 (27.1,27.5)	28.7 (28.5,28.9)	29.5 (29.3,29.7)	30.7 (30.4,30.9)	32.6 (32.3,32.8)
1940s	28.9 (28.3,29.5)	30.5 (29.9,31.2)	31.4 (30.8,32.2)	32.9 (32.2,33.6)	34.7 (34.0,35.5)
1950s	29.5 (37.7,31.2)	31.0 (29.0,33.0)	32.3 (30.5,34.3)	32.7 (30.5,34.8)	35.2 (33.0,37.1)
			United States-Women		
1930	32.3	31.4	32.4	33.4	36.2
1960	28.3	29.7	32.4	33.1	41.9
			United States-Men		
1930	26.6	27.2	28.1	29.8	31.7
1960	26.1	28.3	33.4	37.8	38.8

Note: Canadian data are from the OCA administrative file of the Canada Pension Plan. We report the projected life expectancy by decade of birth, with simulated 95 per cent confidence interval in parentheses reported below. We have all birth years in the 1930s and 1940s. We include 1923–1929 for the 1920s and 1950-1955 for the 1950s. American projections are from National Academies of Sciences, Engineering, and Medicine (2015), based on data from the Health and Retirement Study.

We compare our results to the United States for men in the bottom two panels of Table 2 and in Figure 3, where we reproduce the headline results from National Academies of Sciences, Engineering, and Medicine (2015, p. 3) which compares projected life expectancies conditional on age 50 for Americans born in 1930 with those born in 1960. There was no growth in American longevity in the bottom two quintiles. In contrast, gains in the fifth quintile were projected at 7.1 years. For a comparable 30-year time span, we present on the right-hand side of the figure the results from Canada for the first and fifth quintiles between the 1920s and 1950s for men, along with bars indicating the 95 percent confidence interval. Unlike the United States, there is a statistically significant gain in longevity in the bottom quintile. The 5.1 year gain in the top Canadian quintile is of comparable magnitude to the first Canadian quintile, but less than the analogous American top quintile gain of 7.1 years.

Figure 3: Longevity gains for men in United States and Canada



Note: Data for Canada are from the OCA administrative file of the Canada Pension Plan, and from Figure S1 from National Academies of Sciences, Engineering, and Medicine (2015, p. 3) for the United States. Samples includes only those who survived to age 50. The first and fifth quintiles are shown for each country.

To summarize our results, in Tables 3 and 4 we present regression estimates to characterize the general relationship of life expectancy across birth cohorts and earnings ventiles. In the first column of Tables 3 and 4, we only use those cohorts for which survival is observable up to age 75. Here, we see the top-to-bottom ventile gradient of life expectancy is 3.4 years, and 7.8 years for men. The estimates for the top-to-bottom ventile gradients are slightly higher when the estimates of all cohorts' life expectancy are included (as in column 2). The third and fourth columns present results for survival to age 75, with similar top-to-bottom ventile gradients as estimated for life expectancy. Overall, these results demonstrate there are large and substantial differences in life expectancies across earnings groups.

For context, we compare our results to the life expectancy gradients appearing in Chetty et al. (2016), although there are important differences in the methodology (which we explore later in the paper). For the period 2001–2014 between the top and bottom ventiles Chetty et al. (2016) find gradients of 7.9 years for women and 11.9 years for men.[16] So, if we take our cohort-based measure and the Chetty et al. (2016) cross-section measure as comparable, the magnitude of the life expectancy gradient in Canada is about 75 percent of the value in the United States for men, and 54 percent for women. Below in Section 6.2 we assess the comparability of the cohort-based and cross-sectional methodologies.

[16] We calculate the Chetty et al. (2016) ventiles by averaging the projected life expectancies across the five percentiles in each ventile reported in the data in their online data appendix for Table 2.

Table 3: Regression results (OLS), Women

	Life Expectancy				Survival Age 75			
	(1)		(2)		(3)		(4)	
Constant	30.76	(0.12)***	30.52	(0.41)***	0.762	(0.004)***	0.739	(0.007)***
Ventile								
2	-0.01	(0.15)	-0.03	(0.41)	-0.006	(0.004)	0.003	(0.007)
3	0.79	(0.15)***	0.77	(0.41)	0.003	(0.004)	0.017	(0.007)*
4	0.99	(0.15)***	0.88	(0.41)*	0.001	(0.004)	0.018	(0.007)**
5	0.81	(0.15)***	1.13	(0.41)**	0.006	(0.004)	0.026	(0.007)***
6	1.50	(0.15)***	1.48	(0.41)***	0.010	(0.004)*	0.029	(0.007)***
7	1.29	(0.15)***	1.63	(0.41)***	0.007	(0.004)	0.033	(0.007)***
8	1.80	(0.15)***	2.01	(0.41)***	0.014	(0.004)**	0.039	(0.007)***
9	1.77	(0.15)***	1.94	(0.41)***	0.016	(0.004)***	0.040	(0.007)***
10	1.63	(0.15)***	1.92	(0.41)***	0.016	(0.004)***	0.040	(0.007)***
11	1.60	(0.15)***	2.56	(0.41)***	0.015	(0.004)**	0.050	(0.007)***
12	1.81	(0.15)***	2.54	(0.41)***	0.019	(0.004)***	0.050	(0.007)***
13	1.72	(0.15)***	1.97	(0.41)***	0.018	(0.004)***	0.044	(0.007)***
14	1.67	(0.15)***	1.70	(0.41)***	0.016	(0.004)***	0.039	(0.007)***
15	1.76	(0.15)***	2.26	(0.41)***	0.017	(0.004)***	0.049	(0.007)***
16	1.87	(0.15)***	1.15	(0.41)**	0.018	(0.004)***	0.032	(0.007)***
17	2.01	(0.15)***	2.36	(0.41)***	0.023	(0.004)***	0.053	(0.007)***
18	2.35	(0.15)***	3.24	(0.41)***	0.027	(0.004)***	0.066	(0.007)***
19	3.07	(0.15)***	3.56	(0.41)***	0.041	(0.004)***	0.074	(0.007)***
20	3.42	(0.15)***	3.55	(0.41)***	0.050	(0.004)***	0.076	(0.007)***
Year of birth								
1926-1928	0.44	(0.09)***	0.44	(0.41)	0.010	(0.003)***	0.010	(0.007)
1929-1931	1.03	(0.09)***	1.03	(0.40)*	0.020	(0.003)***	0.020	(0.007)**
1932-1934	1.43	(0.09)***	1.43	(0.40)***	0.031	(0.003)***	0.031	(0.007)***
1935-1937	2.17	(0.08)***	2.17	(0.39)***	0.042	(0.003)***	0.042	(0.007)***
1938-1940	2.53	(0.08)***	2.53	(0.38)***	0.049	(0.002)***	0.049	(0.006)***
1941-1943			2.90	(0.36)***			0.057	(0.006)***
1944-1946			3.29	(0.36)***			0.069	(0.006)***
1947-1949			4.27	(0.35)***			0.087	(0.006)***
1950-1952			3.82	(0.34)***			0.084	(0.006)***
1953-1955			3.53	(0.34)***			0.079	(0.006)***

Note: Regression of life expectancy (or survival rate) on cohort and ventile dummies uses 20 data points for each of the 3-year birth cohorts represented. Standard errors are in parentheses. Number of observations in each cell used as weights.

Table 4: Regression results (OLS), Men

	Life Expectancy		Survival Age 75	
	(1)	(2)	(3)	(4)
Constant	23.15 (0.10)***	23.16 (0.29)***	0.484 (0.003)***	0.490 (0.006)***
Ventile				
2	1.44 (0.12)***	1.35 (0.32)***	0.045 (0.004)***	0.045 (0.006)***
3	2.07 (0.12)***	1.80 (0.32)***	0.065 (0.004)***	0.058 (0.006)***
4	2.40 (0.12)***	1.95 (0.32)***	0.075 (0.004)***	0.064 (0.006)***
5	2.27 (0.12)***	2.37 (0.32)***	0.082 (0.004)***	0.078 (0.006)***
6	2.84 (0.12)***	2.66 (0.32)***	0.094 (0.004)***	0.086 (0.006)***
7	2.94 (0.12)***	3.01 (0.32)***	0.099 (0.004)***	0.095 (0.006)***
8	3.09 (0.12)***	2.68 (0.32)***	0.107 (0.004)***	0.092 (0.006)***
9	3.20 (0.12)***	2.92 (0.32)***	0.112 (0.004)***	0.100 (0.006)***
10	3.54 (0.12)***	3.84 (0.32)***	0.122 (0.004)***	0.121 (0.006)***
11	3.84 (0.12)***	3.83 (0.32)***	0.129 (0.004)***	0.124 (0.006)***
12	4.16 (0.12)***	3.93 (0.32)***	0.140 (0.004)***	0.129 (0.006)***
13	4.28 (0.12)***	4.00 (0.32)***	0.145 (0.004)***	0.135 (0.006)***
14	4.51 (0.12)***	4.61 (0.32)***	0.151 (0.004)***	0.147 (0.006)***
15	4.93 (0.12)***	5.14 (0.32)***	0.163 (0.004)***	0.161 (0.006)***
16	5.38 (0.12)***	5.72 (0.32)***	0.175 (0.004)***	0.173 (0.006)***
17	5.69 (0.12)***	5.87 (0.32)***	0.185 (0.004)***	0.181 (0.006)***
18	6.22 (0.12)***	6.47 (0.32)***	0.202 (0.004)***	0.195 (0.006)***
19	6.94 (0.12)***	6.93 (0.32)***	0.221 (0.004)***	0.209 (0.006)***
20	7.76 (0.12)***	8.06 (0.32)***	0.241 (0.004)***	0.233 (0.006)***
Year of birth				
1926-1928	0.74 (0.07)***	0.74 (0.27)**	0.022 (0.002)***	0.022 (0.005)***
1929-1931	1.49 (0.07)***	1.49 (0.26)***	0.046 (0.002)***	0.046 (0.005)***
1932-1934	2.25 (0.07)***	2.25 (0.27)***	0.071 (0.002)***	0.071 (0.005)***
1935-1937	3.20 (0.07)***	3.20 (0.27)***	0.100 (0.002)***	0.100 (0.005)***
1938-1940	3.92 (0.07)***	3.92 (0.26)***	0.119 (0.002)***	0.119 (0.005)***
1941-1943		4.39 (0.26)***		0.133 (0.005)***
1944-1946		5.10 (0.25)***		0.155 (0.005)***
1947-1949		5.08 (0.24)***		0.158 (0.005)***
1950-1952		5.01 (0.24)***		0.160 (0.005)***
1953-1955		5.23 (0.24)***		0.163 (0.005)***

Note: Regression of life expectancy (or survival rate) on cohort and ventile dummies uses 20 data points for each of the 3-year birth cohorts represented. Standard errors are in parentheses. Number of observations in each cell used as weights.

5.3 Summary of main results

In this section, we have presented two main significant results. First, we have documented the existence and magnitude of survival and life expectancy gradients across the earnings distribution for Canada. Our regression findings of an 8.1 year difference between high and low earning men and 3.6 years for women are large and economically significant. Our findings provide context for the recent results for the United States in Chetty et al. (2016), and extend significantly the early work of Wolfson et al. (1993) using similar Canadian administrative data. Second, we have shown that longevity has evolved very differently in Canada compared to the United States. Our finding of a uniform shift in Canadian longevity across the earnings distribution is in sharp contrast to the experience of the United States where several researchers have found sharply steepening longevity gradients (Auerbach et al. 2017, Bosworth et al. 2016, Chetty et al. 2016, Cristia 2007, National Academies of Sciences, Engineering, and Medicine 2015, Olshansky et al. 2012, Waldron 2007, Waldron 2013).

6 Extended results

We extend our results to examine the special case of middle-age males, compare results using cohort-based and cross-sectional methodologies, and explore the impact of earnings growth on our longevity findings. This extended analysis offers additional depth and context to our results and facilitate comparisons with recent findings in the United States.

6.1 Survival rates of middle-aged males

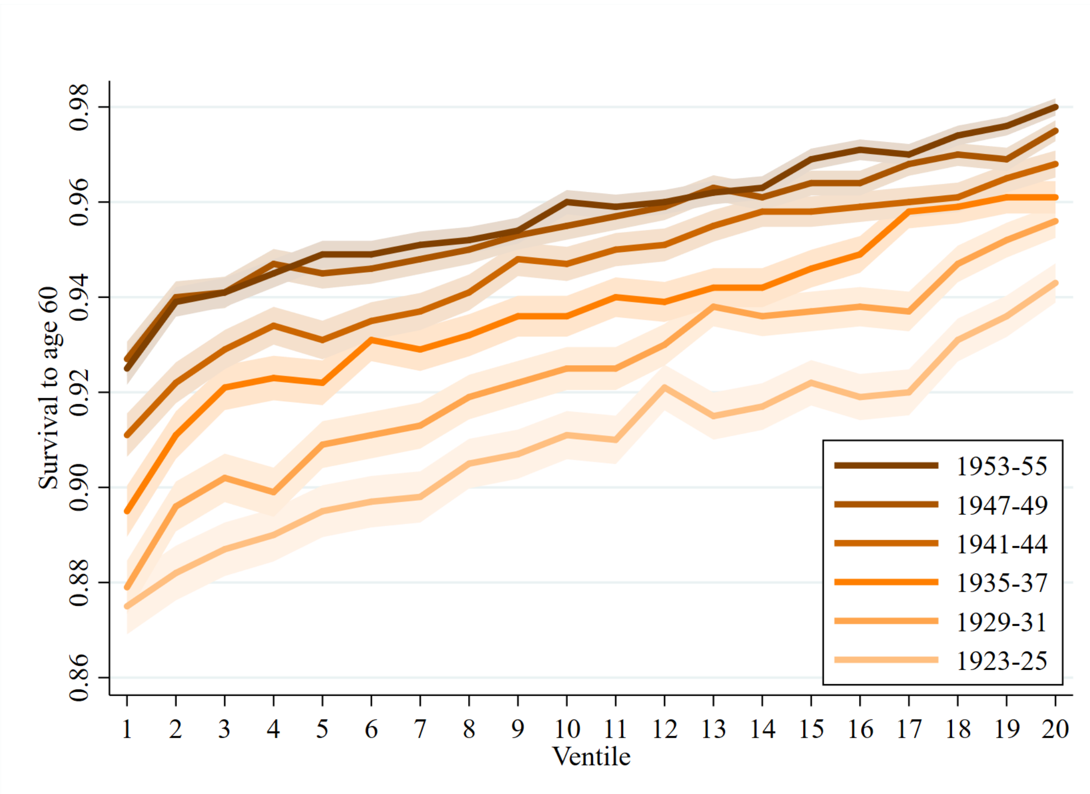
We draw a subset of our data to make explicit comparisons to the work of Case and Deaton (2015, 2017) for the United States, which uncovered a rise in mortality rates for non-Hispanic white middle-aged males between the years 2000 and 2015. The heightened "deaths of despair" from drugs, alcohol, and suicide may reflect economic or social factors that also manifest in Canada. The Canadian economy since 2000 overall has followed a different path than the United States, with a natural resources boom that boosted the labor market in some regions.[17] On the other hand, regions with a traditional manufacturing base have been affected similar to manufacturing

[17] Milligan and Schirle (2017) provides a comparison of the Canadian and American labour market outcomes in the 1990s and 2000s.

regions in the United States. In addition, the rise of opioids in Canada has mirrored trends in the United States (Fischer et al. 2016).

To attempt a comparison to the findings from the United States, we select data on survival rates between the ages of 50 and 60 for males. Our data do not allow us to make similar ethnic or racial selections, nor to pull out different geographies. So, the comparison of our sample to Case and Deaton (2015, 2017) is therefore imperfect.

Figure 4: Age 60 survival for males by 3-year cohort



Note: Data are from the OCA administrative file of the Canada Pension Plan. We show the survival at age 60 conditional on survival to age 50, with calculated 95 percent confidence intervals shaded.

We graph survival rates in Figure 4 using birth cohorts of males in three year groupings from 1923–1925 to 1953–1955. We show only every 2nd group of three years in order to keep the presentation of results clear. The calculated 95 percent confidence interval is indicated with shading, becoming smaller across cohorts because of increased cohort size. We focus on survival rates rather than life expectancies to keep the comparison with Case and Deaton (2015, 2017) tight and also because we are able to use observed data without reliance on more-variable projections of life expectancy.

The survival rates until the 1950s reveal a pattern similar to the main results presented earlier—a clear upward gradient in survival with earnings, and a clear upward progression across birth cohorts. However, the results for the 1952-1955 cohort are remarkably different. The survival rates are right on top of the 1947–1949 birth cohorts at lower earning ventiles, only rising significantly above the previous cohort group in the 19th and 20th ventile. We do not observe any reversal in mid-age male survival, but we do observe a sudden cessation of survival improvements. As these cohorts age and younger cohorts enter the middle-age range, it will be interesting to see if this emerging change in survival rates persists as further data on these cohorts become available.

6.2 Cohort and cross-section life expectancy

Standard measures of mortality, survival, and life expectancy are based on cross-sectional methods. In any given year, deaths are compared to population at risk and then aggregated across ages to form survival rates. Often, though, measures based on the actual lifetime experience of cohorts would be superior if available, since we often want to know how social or economic forces have changed the life trajectories of those affected by shocks. Cohort-based measures require both longitudinal capturing of data and very long time periods, both of which present often-insuperable challenges. So, a better understanding of the efficacy of cross-sectional methods as an easier-to-calculate proxy for cohort survivor rates would provide stronger support for their use.

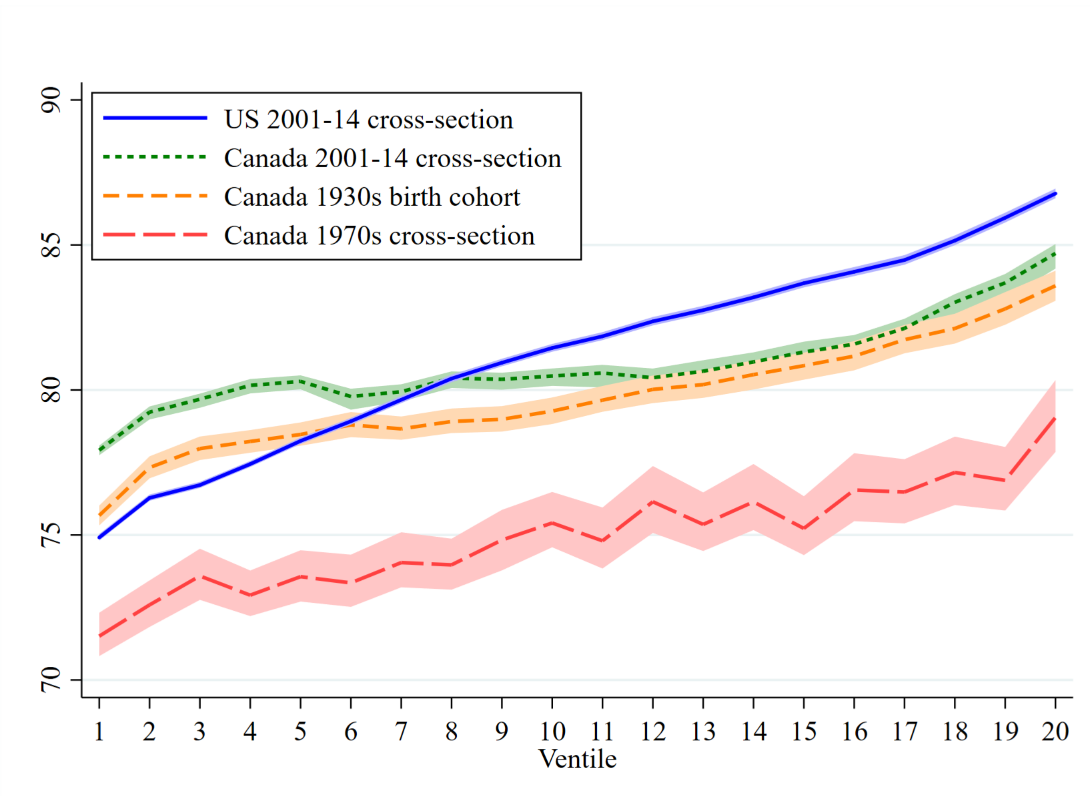
The recent paper by Chetty et al. (2016) makes use of cross-sectional methods to generate life expectancies. Using income lagged two years to assign income quantiles, each year's observations for each sex and quantile are used to form age-specific survival rates. These survival rates are then projected to older ages using a similar Gompertz approach to what we used in this paper. In comparing our results to Chetty et al. (2016), a natural question arising is whether the difference between cohort-based and cross-sectional methodologies underlies any differences in our findings. We pursue this question in this subsection.

We form blocks of survival rates using the Chetty et al. (2016) methodology for each year, sex, and quantile of earnings.[18] Because we have data stretching back to 1966, we can implement the methodology over almost the entire 50 years of our data. To make the comparison to Chetty et al.

[18]We continue to use earnings rather than family income to characterize the income distribution because our data does not include other non-earning sources of income. So, our implementation of the Chetty et al. (2016) methodology is imperfect.

(2016) tight, we draw a sample covering the same years: 2001 to 2014. We supplement this time range with an additional sample from the 1970s (1970–1979) in order to see whether our "uniform shift" finding can be replicated using the cross-sectional methodology.

Figure 5: Life expectancy using different methodologies



Note: Data for Canada are from the OCA administrative file of the Canada Pension Plan. Data for the United States are from Figure 2 in Chetty et al. (2016). The lines here show life expectancy conditional on survival to age 50—except for the U.S. 2001–14 line which is conditional on survival to age 40. Shaded areas show simulated 95 percent confidence intervals.

The results are shown in Figure 5. We focus here exclusively on men since differential selection of women in the Canadian data would complicate the comparison. We graph the life expectancies from Figure 2 of Chetty et al. (2016) for the U.S. for 2001–2014 alongside our Canadian data for 2001–2014. To note, the U.S. data is conditional on survival to age 40 while the Canadian data is conditional on survival to age 50. The figure also shows the Canadian cross-sectional results for the 1970s and the cohort-based results for those born in the 1930s.

There are three relevant and revealing comparisons in Figure 5. Using a similar methodology and 2001–2014 time frame, the gradient in the United States remains steeper than Canada, with lower survival at lower income levels in the United States but higher survival at high income levels. Second, comparing the two Canadian cross-sectional lines, it is clear that the "uniform shift" result in our cohort-based methodology also manifests in the cross-sectional approach. So, the different evolution of longevity in Canada and the United States cannot be attributed to differences in methodology. Finally, there is a strong indication that the gradient for Canada using the cohort-based approach is steeper than with the cross-sectional approach. The difference in slope is 0.08 years per ventile, which adds to 1.6 years over the 20 ventiles.[19] So, the cohort-based slope is 28 percent steeper than the cross-sectional slope. This may suggest that the income-longevity gradient found in Chetty et al. (2016) understates the actual experience of cohorts across time.

6.3 Comparisons across earnings distributions

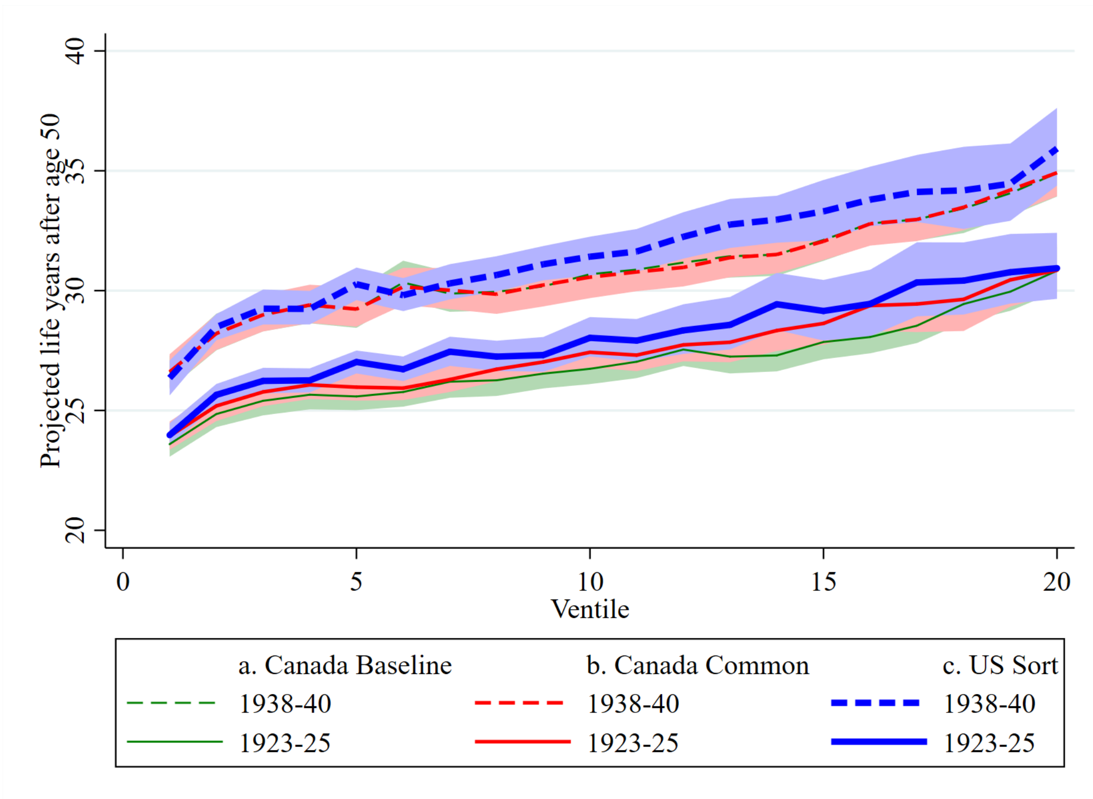
Some of the differences in earnings-longevity gradients we have documented across cohorts and countries may be a result of differences in the shape and position of the earnings distribution. For example, some of the observed changes in longevity over time may be driven by higher earnings of later cohorts. Similarly, the higher longevity at high quantiles in the United States might result from the higher levels of income necessary to attain a high quantile ranking in the United States—if we compare similarly-high earning Canadians we can assess the importance of differences in earnings to the observed longevity gradients. In both cases, we can assess these possibilities by re-sorting our data using common earning thresholds across cohorts and countries. We pursue this re-sorting analysis for men in Figure 6.

Our analysis embeds three sets of lines in Figure 6. The first set of lines is a baseline earnings-longevity gradient for the 1923–25 and 1938–40 cohorts of men, matching the estimates of life expectancy represented in Table 4. This is labeled as "Canada Baseline." As before, we observe a fairly uniform shift in life expectancy of about four years across earnings ventiles between those born in 1923–25 and 1938–40.

The second comparison in Figure 6 takes the same two birth cohorts, but re-sorts them into ventiles based on earnings thresholds that are common across all birth cohorts. To do so, we include all men across our sample from 1923–1955 and find the earnings ventile cutoffs based on this common sample. So, with any earnings growth, some top-ventile men born in 1923–1925 may be re-sorted

[19] We run a regression of the life expectancy on a linear ventile term and a linear ventile term interacted with a dummy for cohort-based estimates. The resulting coefficient on the differential slope is -0.079 (0.032).

Figure 6: Male life expectancy using different earnings distribution thresholds



Note: Data for Canada are from the OCA administrative file of the Canada Pension Plan. Thresholds for the 20 income groups (ventiles) are based on (a) each 3-year year of birth cohort in Canada, (b) the full sample of Canadians born 1925-1955, or (c) 3-year year of birth cohorts in the United States based on tabulations using the Current Population Survey. Shaded areas indicate 95 percent confidence intervals.

downward if they no longer surpass the higher earnings threshold based on the common sample. These results are labeled "Canada Common." For the 1923–1925 cohort at the bottom, there is a small change when the data are re-sorted. For the later 1938–1940 cohort, the re-sorted data with the common thresholds is very close to the baseline data. The explanation for this small change is the lack of earnings growth in these particular cohorts. The 1925 birth cohort was age 50 in 1975 and the 1940 birth cohort was age 50 in 1990. This period was one of generally stagnating male earnings, so the re-sorting had little effective change on quantile rankings.[20]

The third comparison in Figure 6 compares the baseline results to a re-sort that uses ventile

[20]See Lemieux and Riddell (2016) for evidence on income growth between 1982 and 2010. While there was large growth in the top part of the top one percent of the income distribution, growth in the bottom 90 percent was negligible.

thresholds based on earnings in the United States.[21] The distribution of earnings is clearly wider in the U.S. than in Canada, so that as high-survival Canadian men are re-sorted into lower ventile groups, those remaining in the higher ventiles have better longevity. Moreover, as men are re-sorted out of the high earnings ventile downward, they pull up the longevity compared to the baseline sort. However, when we apply this re-sort these differences are insignificant and fairly small compared to the differences across cohorts.

Overall, we interpret these findings as suggesting that while cross-country and through-time differences in the earnings distribution will affect our estimates of the earnings-longevity gradient, these differences are small and factors other than earnings levels are the primary driver of longevity differences we have documented in our baseline analysis.

7 Discussion

Our results reveal a sharp difference in the evolution of longevity in Canada and the United States. While longevity gains have been concentrated in the top half of the earnings distribution in the United States, we find fairly uniform gains across the earnings distribution for Canada. In this section, we discuss several possible explanations for this finding. Of course, causally isolating factors that explain this broad cross-cohort change is difficult and we don't attempt it here. Instead, the discussion aims to set the stage for deeper investigations of possible causal channels by interpreting our findings in the context of existing theory and evidence.

Lleras-Muney and Moreau (2018) provides a useful theoretical framework for this discussion. In their model, mortality at a point in time is a function of 'frailty'. Individuals receive an initial endowment of frailty as in Vaupel et al. (1979). However, the Lleras-Muney and Moreau (2018) model then adds dynamics like the Grossman (1972) health capital model: investments, shocks, and depreciation that shifts the initial endowment of frailty period by period as one ages. The main implication of the model is that the probability of mortality at any time depends on the history of shocks and investments over one's lifetime.

Our discussion proceeds by considering three possible explanations for the different evolution of the longevity gradient in Canada and the United States: health insurance, education and information

[21] These earnings thresholds are calculated using average age 45–49 earnings in the Current Population Survey for each birth cohort, using survey years 1968–2004 for cohorts ranging from 1923–1925 to 1953–1955. We adjust these earnings by inflation and the U.S.-Canada exchange rate and find the ventile cutoffs. We then attach these U.S. cutoffs to our Canadian data by cohort.

processing, and long-run stress and hardship.

The first possibility we consider is health insurance differences between Canada and the United States. While an obvious place to start the comparison, several factors weigh against this explanation. First, the Lleras-Muney and Moreau (2018) model suggests caution in expecting health insurance near the end of life to have much impact, since the accumulated stock of frailty is more affected by things that occur earlier in life than the insurance available at a certain point in time. Second, Cutler et al. (2006) argue that the empirical evidence does not support health insurance improving mortality at older ages.[22] Third, the birth cohorts we consider in Canada were born well before the wide-spread introduction of universal public health insurance in Canada in the 1960s.[23] These three arguments tend to downgrade the importance of health insurance as an explanation for the Canada–US difference in the longevity gradient.

Another possible source of the mortality gradient in the United States is education and how information is processed into health behaviors.[24] Cutler et al. (2006, p. 115) argues that education mediates the diffusion of health information and technological change, leading them to predict (p. 117) that the pace of technological change in health will lead to a steepening mortality gradient. However, Cutler et al. (2011) find that changes in health behaviors alone cannot explain the growing gap. Instead, it is growth in the consequences of negative health behaviors that underlies education differences. Recent evidence suggests that differences in health behaviors may have substantial long-run impact on survival after age 50 (Li et al. 2018). Beyond education, many argue that poverty directly impairs cognitive judgement and choices that are made.[25] Increased cognitive loads could also affect the adaptation of health information in the same way as lower education. However, for the information and health behavior explanation to hold, Canada–U.S. differences in education and cognition across the whole bottom half of the lifetime earnings distribution would need to be evolving in sharply different directions.

[22] See, for example, Finkelstein and McKnight (2008) for evidence from the introduction of Medicare in the United States. There was no estimated effect on mortality, although there was a substantial impact on out-of-pocket health expenses.

[23] See Hanratty (1996) and the references cited therein for a history of the introduction of public health insurance in Canada.

[24] Elo and Preston (1996) document mortality differentials by education in the U.S. from 1979-1985. See Lleras-Muney (2005) for causal evidence of the relationship between education and mortality. Meara et al. (2008) document the central role of education in the changing mortality gap, finding that almost all gains in mortality are accruing to higher-educated Americans. Olshansky et al. (2012) argue that race and educational differences are central to the widening mortality differences. Bound et al. (2015) adds caution because of the changing composition of education groups through time, but still finds that lower-educated Americans are not sharing in mortality improvements.

[25] See Schilbach et al. (2016), Haushofer and Fehr (2014) and Mani et al. (2013) for theory and evidence on the psychological link between poverty and cognition.

The final explanation to consider is long-run stress and hardship. Cutler et al. (2006, p. 114) discuss evidence linking mortality and psychosocial stress from being in a low-status or subservient position with little control over important decisions. Bio-psychological reactions to such circumstances can build up an allostatic load through constant exposure to stress hormones like cortisol.[26] In the Lleras-Muney and Moreau (2018) model, the continuing drag of a heightened allostatic load would speed up health depreciation and increase mortality. The social safety net in Canada is presently more generous to those at the bottom of the distribution than in the United States.[27] However, it is not clear this gap favored Canada in the middle part of the twentieth century when several of the cohorts we study had already entered adulthood. Moreover, wages for those who are working in Canada were lower over the lifetime of the birth cohorts we consider, so it's not clearly the case that lifetime economic resources were sufficiently different over the bottom half of the earnings distribution to explain the difference in longevity trends. On the other hand, stressful considerations such as violent crime and unavailability of health insurance experienced over decades could in principle act through the allostatic channel to wear down health and increase mortality.

8 Conclusion

In this paper, we study the relationship between earnings and longevity using a comprehensive administrative dataset of Canadian men and women spanning a half century. We find that the gap in life expectancy between the lowest and highest earners is about eight years for men—an 11 percent difference in lifespan. This is about 75 percent of the steepness of the gradient found recently by Chetty et al. (2016) for the United States. In sharp contrast to the United States, however, evolution of this earnings-longevity gradient has been a mostly-uniform shift, with equal improvements among high and low earners. Improvements in survival for middle age men in Canada have stopped upward progress for those born in the 1950s, echoing results of Case and Deaton (2015, 2017). We still find a similar gradient and uniform shift when applying the Chetty et al. (2016) cross-sectional methodology to our data, although the slope of the gradient is flatter when using the cross-sectional methodology compared to the cohort-based measure. Finally, we consider the importance of widening earnings distributions and suggest that changes to the earnings distribution may have only small impacts on the earnings-longevity gradient. The paper closes with

[26] The concept of allostasis originates in McEwen and Stellar (1993) and describes the accumulating wear and tear on the body of chronic stress.

[27] See Hoynes and Stabile (2017) for the case of families with children.

a discussion of several possible explanations for the Canada-U.S. difference, ranging from health insurance to education and health behaviors to stress and hardship. We conclude by noting that neither theory nor evidence provides a clear indication which of these explanations may hold. As the relationship between longevity and earnings is fundamental to the distribution of older-life wellbeing and the design of social programs, understanding the sources pushing the evolution of longevity should be a priority for future research.

A Appendix: Sample selection

This appendix presents and discusses evidence related to sample selection decisions.

A.1 Sample selection decisions

The selection decisions we imposed on our data appear below in Table A1.

Table A1: Sample Selection

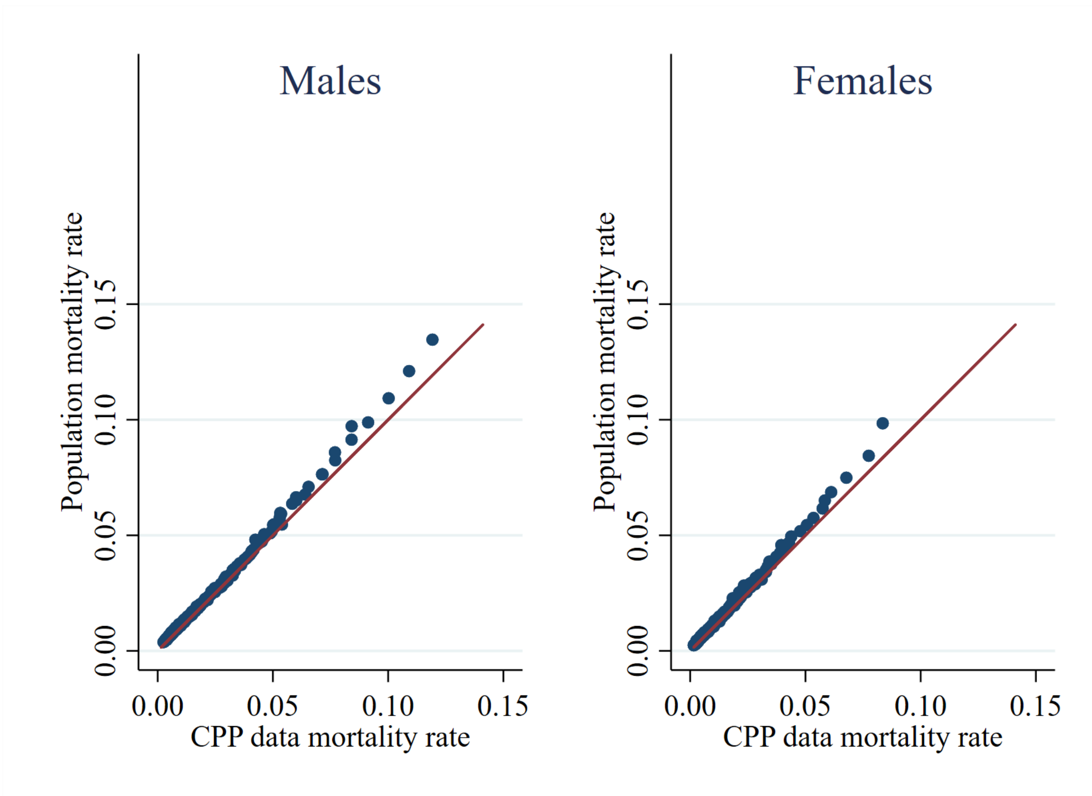
Description	Count
Starting sample	11,078,445
Death in Earnings but not in Benefits database	30
Death in Benefits but not Earnings database	360
Death inconsistent between Earnings and Benefits databases	345
Birth year inconsistent between Earnings and Benefits databases	10,275
Gender inconsistent between Earnings and Benefits Databases	3,325
Death in Disability but not Earnings databases	40
Death year inconsistent between Earnings and Disability databases	45
Birth year inconsistent between Earnings and Disability databases	1,120
Gender inconsistent between Earnings and Disability Databases	590
Drop if benefits final termination reason is non-conforming	8,800
Drop if born 1920 or earlier since we need age 45 earnings	708,185
Drop if died at 50 or earlier	287,645
Drop Likely Quebec Pension Plan applicants	525,355
Male count at this point	5,051,510
Female count at this point	4,480,835
Drop females if less than 4/5 earnings between ages 45-49	1,697,710
Drop males if less than 4/5 earnings between ages 45-49	1,311,500
Final main sample males	3,740,010
Final main sample females	2,783,120
Final sample total	6,523,130

Note: Data are from the OCA administrative file of the Canada Pension Plan. Numbers rounded to the nearest 5 to conform with confidentiality disclosure requirements.

A.2 Comparison with population mortality

In order to assess the representativeness of our sample, we construct age-year mortality rates separately for men and women for ages 50-100. We compare these to the population mortality rates taken from Canadian Human Mortality Database (2016), aggregated across Canada but excluding residents of the province of Quebec to make the aggregate data comparable to our sample which excludes most Quebec residents. We form similar three-year groups for each data source. The results are presented below in Figure A.2. The correlation for males is 0.999 and for females is 0.996.

Figure A1: Sample vs. Population Mortality Rates

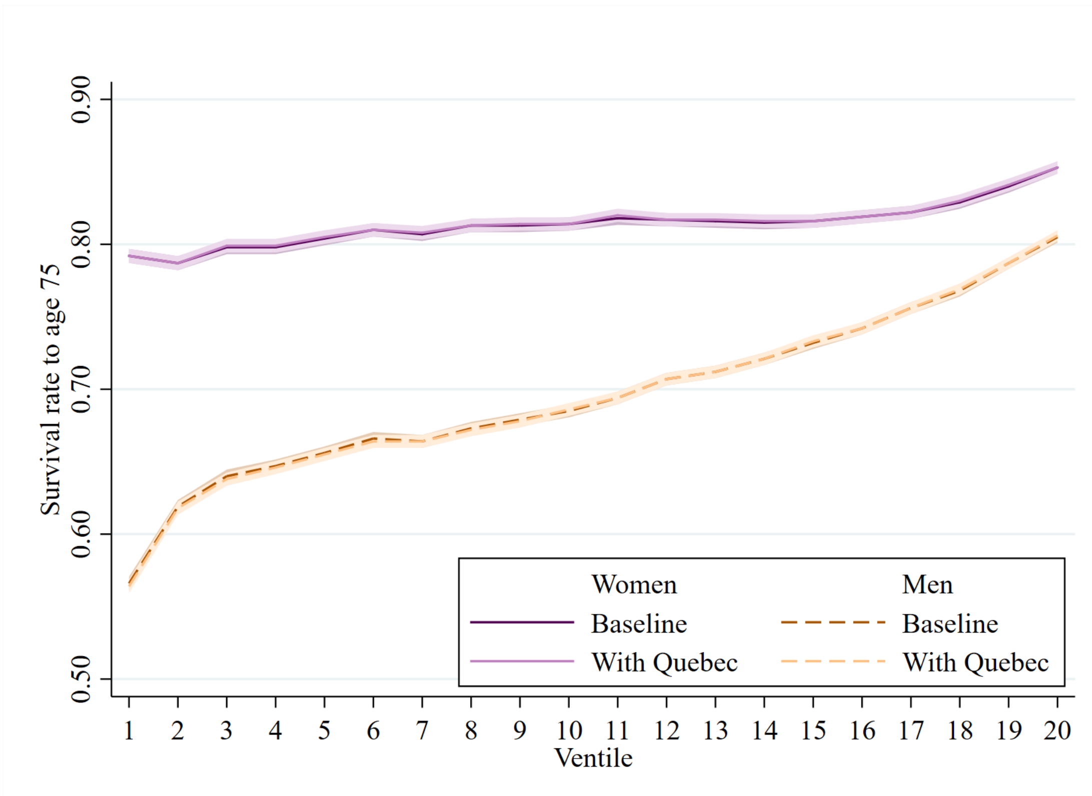


Note: Data are from the OCA administrative file of the Canada Pension Plan and Canadian Human Mortality Database (2016). Age-year-sex period mortality rates are formed in each dataset and plotted against each other.

A.3 Quebec

The province of Quebec operates a parallel and separate Quebec Pension Plan. We observe in our data the lifetime earnings of anyone who has contributed at least once to the Canada Pension Plan. We do not observe the earnings of individuals who only contributed to the Quebec Pension Plan, or the benefit claims of those who apply to the Quebec Pension Plan for benefits. So, to maintain consistency in our data we wish to exclude those from the earnings database who are likely to eventually apply to the Quebec Pension Plan for benefits. The Canada Pension Plan advises individuals who have contributed to both plans over their lifetime to apply for benefits

Figure A2: Age 75 Survival for Samples with Potential Quebec Pension Plan Applicants



Note: Data are from the OCA administrative file of the Canada Pension Plan. The 'With Quebec' sample includes those who are potential Quebec Pension Plan applicants while the baseline sample does not. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Shaded area indicates the 95 percent confidence interval.

based on where they live at the time of application.[28]

In our data, we tag individuals as 'potential Quebec Pension Plan applicants' based on their last observed year of earnings. If there are contributions to both plans in the final year, we use the higher of the two contributions to tag the individual. We remove those tagged as potential Quebec Pension Plan applicants from our data. As seen in Table A1, around 4.75 percent of our sample contributed to both plans.

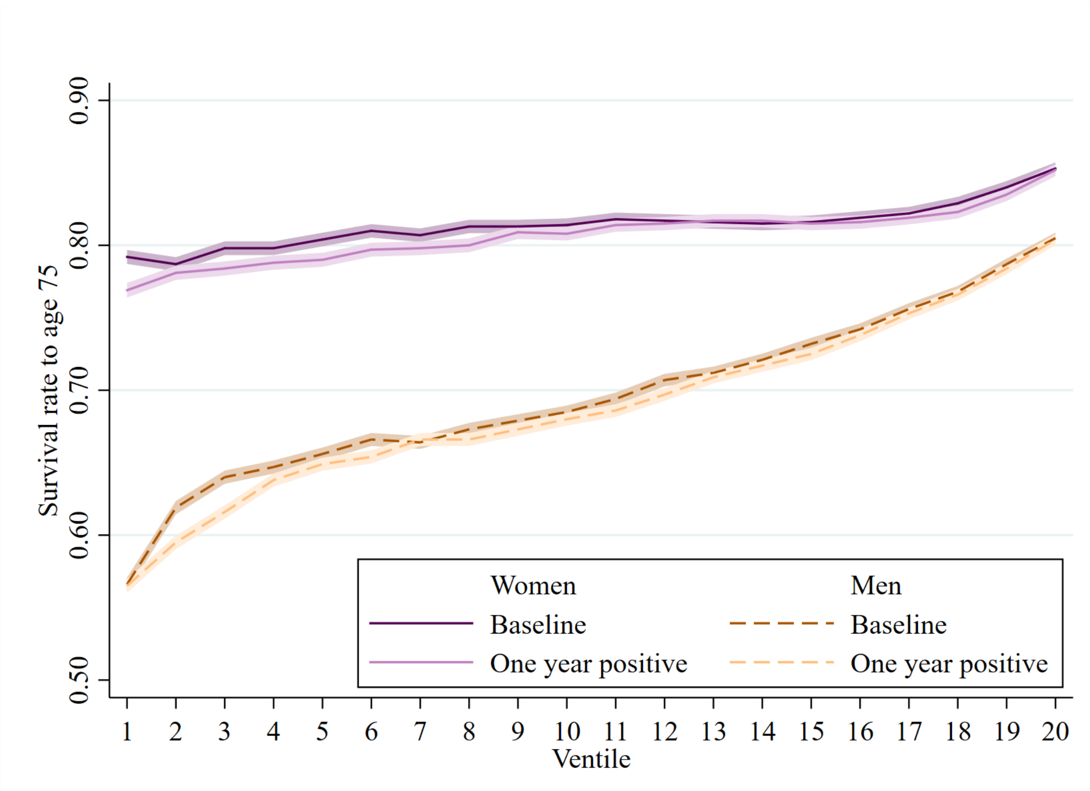
To assess the sensitivity of our results to this decision, in Figure A.3 we plot age 75 survival for men and women for our baseline sample (which excludes the potential Quebec Pension Plan applicants)

[28]The Service Canada website advises applicants: "If you have contributed to both the CPP and QPP, you must apply for the QPP if you live in Quebec or for the CPP if you live elsewhere in Canada." https://www.canada.ca/en/services/benefits/publicpensions/cpp.html

and a sample that includes those potential Quebec Pension Plan applicants. We show the results by lifetime earnings ventile measured as average earnings from age 45-49. The figure uses all Canadians born in the 1930s. It is clear that the differences in mortality across these two samples is very small, which suggests that those contributing to the Quebec plan show approximately the same mortality patterns as those who are most likely Canada Pension Plan applicants.

A.4 Labour market attachment

Figure A3: Age 75 Survival for Samples with Different Earnings Requirements



Note: Data are from the OCA administrative file of the Canada Pension Plan. The 'One year positive' sample requires only one year between ages 45-49 to show positive earnings. The baseline sample requires four out of five years to be positive. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Shaded area indicates the 95 percent confidence interval.

The goal of our analysis is to characterize survival across different levels of lifetime earnings as measured by average earnings between ages 45 and 49. Including those with zero earnings would produce results closer to mortality patterns of the whole population, while requiring a minimum amount of earnings somewhat restricts the sample. In principle the broader sample may be desirable, but our sample includes some who earned at younger ages and then do not earn again and do not claim benefits at older ages. This pattern would occur, for example, if someone earned but never claimed benefits, left the country after a few years of earning, or was in Canada only temporarily. Including such people in the sample would bias survival rates since their death would not be observed. For this reason, we condition our baseline sample on having earnings in at least four of the five years in the age 45-49 range. As can be seen in Table A1, this restriction removes about one quarter of our male sample and over one third of the female sample. We tested weaker restrictions and found that requiring four out of five years best balanced the desire for a broad sample with the need to ensure we include only those who remained in Canada through older ages.

In Figure A3 we show our baseline results and the results for a sample where we only require one year of earnings between ages 45 and 49. The figure displays survival rates to age 75 for men and women born in the 1930s by earnings ventile. For men, the survival rate in the baseline sample is slightly higher until about the 7th ventile and thereafter very close. For women there is a small gap which persists to about the 10th ventile. In both cases the sample requiring only one year to have positive earnings has lower survival.

Below in section B.2 we go into more detail on the problem of permanent survivors to assess how well our labour market attachment condition removes those who may not have their deaths observed.

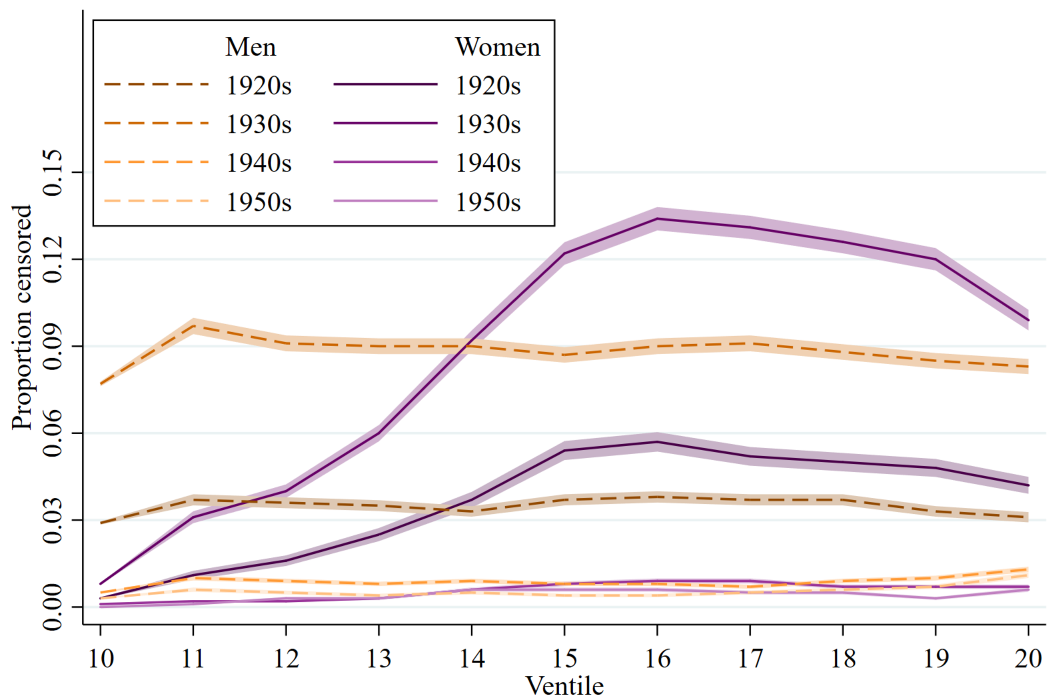
B Appendix: Adjustments to the data

B.1 Top Coding

The annual earnings reported in the data are censored by top-coding in two circumstances. Below we explore the incidence of top-coding and then describe our imputation method and assess the sensitivity of our results.

First, for some years in the 1970s and 1980s a subset of the sample appears to be top-coded at the upper pensionable limit, called the Year's Maximum Pensionable Earnings (YMPE). We are unaware of any statutory reason why earnings would be reported at the YMPE. In Figure B1 we show the proportion of men and women who had at least one year in the age range 45-49 top-coded at the YMPE by decade of birth and earnings ventile. The figure shows a positive incidence reaching around 13 percent for women and 9 percent for men born in the 1930s and levels less

Figure B1: Top Coding at the Year's Maximum Pensionable Earnings

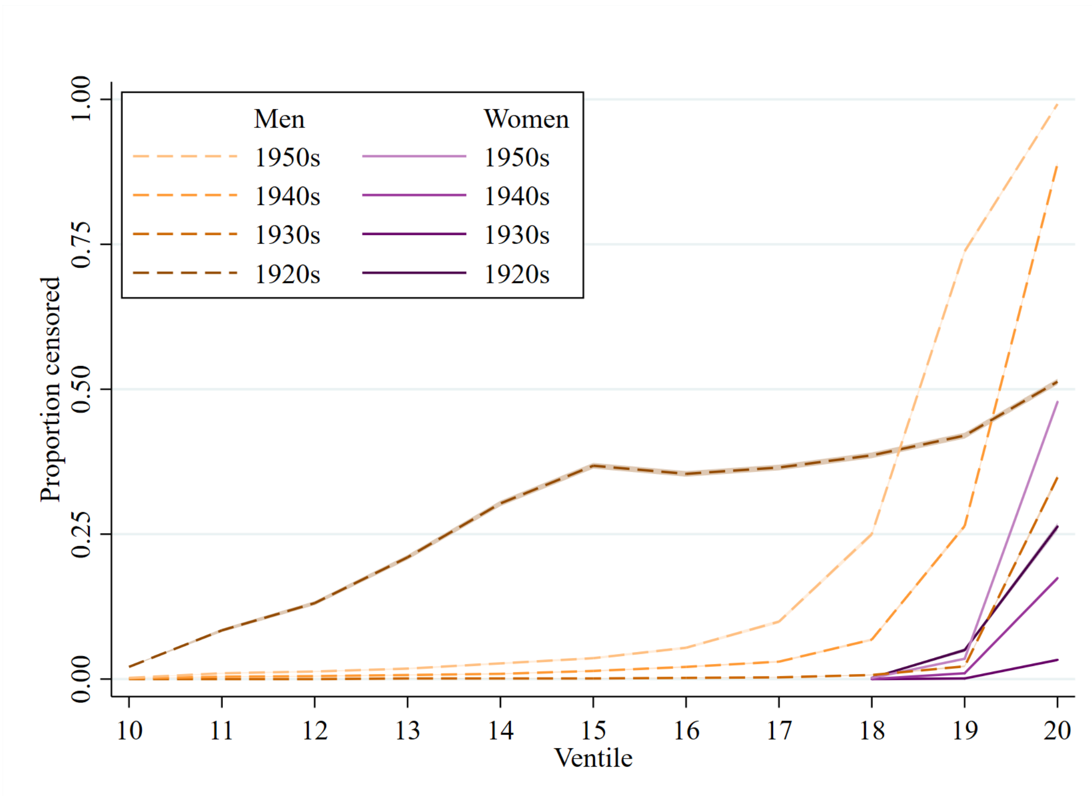


Note: Data are from the OCA administrative file of the Canada Pension Plan. Each line shows the proportion of the sample censored at least once at the Year's Maximum Pensionable Earnings. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Each line for men and women shows those born in different decades as indicated. Shaded area indicates the 95 percent confidence interval.

than half that amount for those born in the 1920s. The incidence for those born in the 1940s and 1950s is negligible. For men, the impact is approximately equal across earnings ventiles, while for women it rises until about the 15th ventile.

The second top-coding issue is a feature of the way earnings were recorded in the earnings database. Until 1971 annual earnings were coded up to four digits, with a maximum value of $9,999. After that year, earnings were reported only up to five digits. In Figure B2 we show the proportion of men and women who had at least one year in the age range 45-49 censored by this digit constraint across ventiles for each decade of birth. For women, very few are censored until the top ventile of lifetime earnings. For men, censoring is fairly widespread at around one third of the sample for those born in the 1920s–those most affected by the four-digit censoring–at mid-range ventiles. For

Figure B2: Top Coding at Four or Five Digits of Earnings

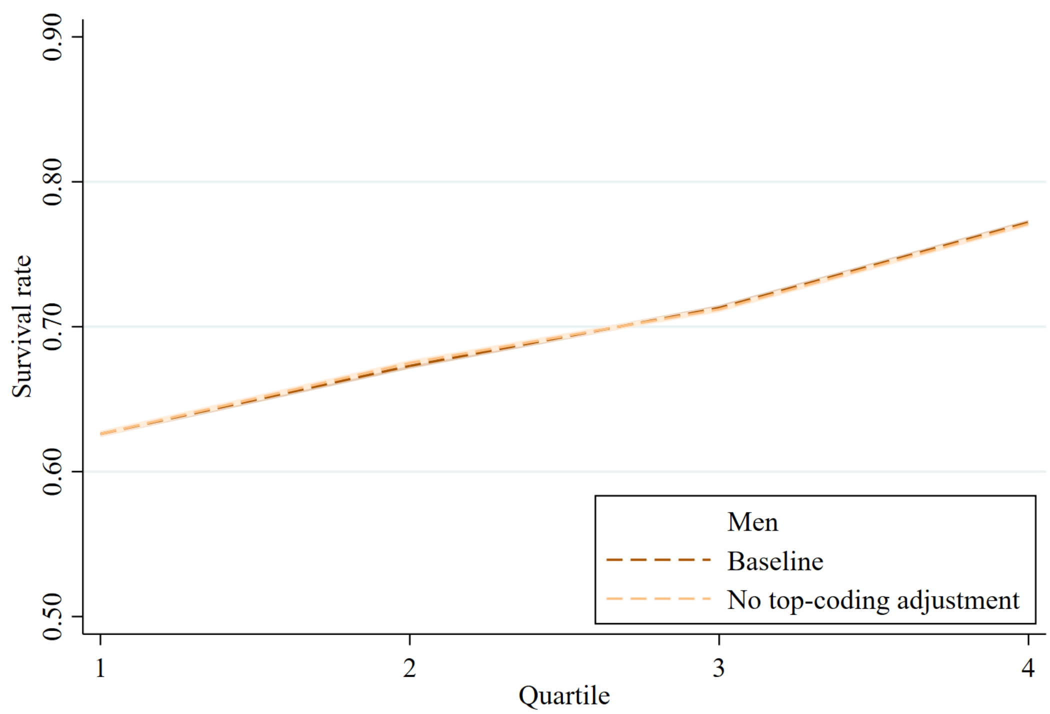


Note: Data are from the OCA administrative file of the Canada Pension Plan. Each line shows the proportion of the sample censored at least once at the four or five digit earnings limit. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Each line for men and women shows those born in different decades as indicated. Shaded area indicates the 95 percent confidence interval.

later cohorts, the five-digit censoring has impact starting around ventile 19 for the 1930s cohort, ventile 17 for the 1940s cohort, and around ventile 15 for the 1950s cohort. By ventile 20 for men, almost all the 1940s and 1950s cohorts had at lease one year censored by the five-digit constraint.

To address these top-coding issues we impute earnings to those who are censored. For each individual, we form a five-element vector of year-over-year real earnings growth rates. For imputing at the four-digit constraint, we use years after the four-digit constraint was removed. For those at the five-digit constraint and the YMPE constraint, we use earlier years to form the vector. We then randomly draw with replacement from this vector and apply the growth rates to a 'jump off' year which is the uncensored year closest to the censored earnings year and calculate an imputed earnings level.

Figure B3: Age 75 Survival for Samples without Earnings Imputations



Note: Data are from the OCA administrative file of the Canada Pension Plan. The 'no top-coding adjustment' sample does not impute earnings above the censoring point, while the baseline sample follows the imputation procedure described in the text. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Shaded area indicates the 95 percent confidence interval.

In Figure B3 we test the impact of our imputation procedure by graphing the age 75 survival rate for all cohorts by earnings quartile.[29] There is almost no perceptible change. This small impact may seem at odds with the incidence of top-coding shown in Figures B1 and B2, but the topcoding just means we re-sort the ranking of lifetime earnings and few individuals change rankings with and without the earnings imputations.

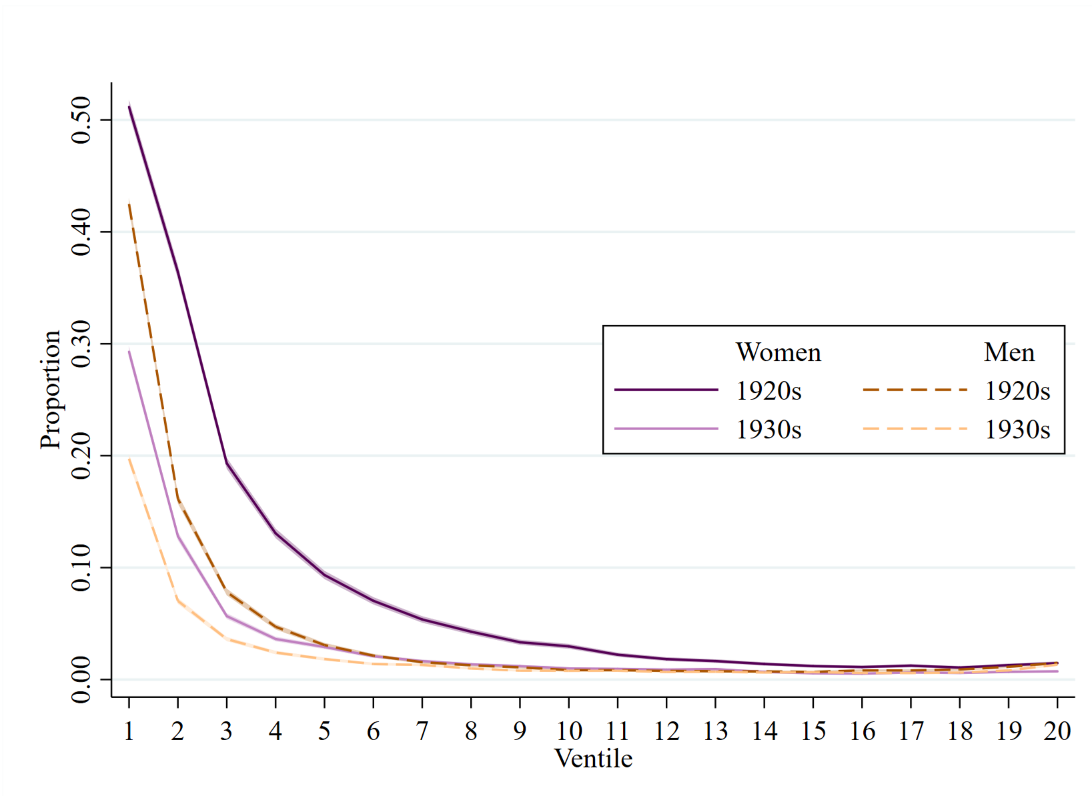
B.2 Permanent survivors

As discussed in Appendix section A.4, some individuals may appear for a few years in the earnings database but are not seen again either in the earnings or the benefits database. This could occur, for

[29]We use quartiles here rather than ventiles because so few observations change in the ventiles that we encounter the minimum-disclosure rule imposed by Statistics Canada on this dataset.

example, if someone earned but never claimed benefits, left Canada permanently before claiming, or lived only temporarily in Canada. In order to minimize the potential bias of including those whose deaths may go unseen, we imposed a requirement of four earnings years between ages 45 and 49.

Figure B4: Proportion Not Appearing in Benefit Database by Age 67

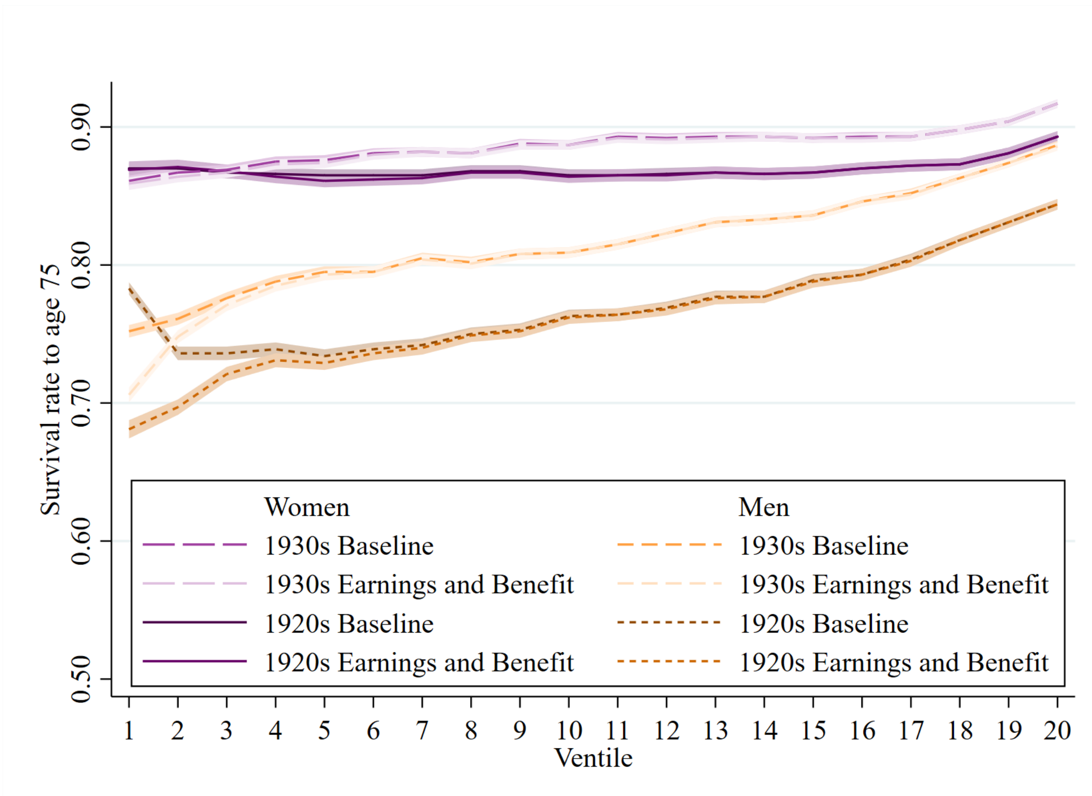


Note: Data are from the OCA administrative file of the Canada Pension Plan. Each line shows the proportion of the sample in the earnings database that survived to age 67 but did not appear in the benefits database. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Each line for men and women shows those born in different decades as indicated. Shaded area indicates the 95 percent confidence interval.

To test for the prevalence of this circumstance, we undertake the following procedure. We take a sample of those in the earnings database who survived to age 67 and check how many appear in the benefits database. Almost all Canada Pension Plan retirement benefits claims are made by age 67 or earlier. If a claim is not made by age 67, we tag the person as a potential 'permanent survivor' since it is unlikely we will observe their death if they are not claiming benefits.

In Figure B4 we show the proportion tagged as permanent survivors for men and women by decade

Figure B5: Age 75 Survival for Samples Excluding Those Never Claiming Benefits



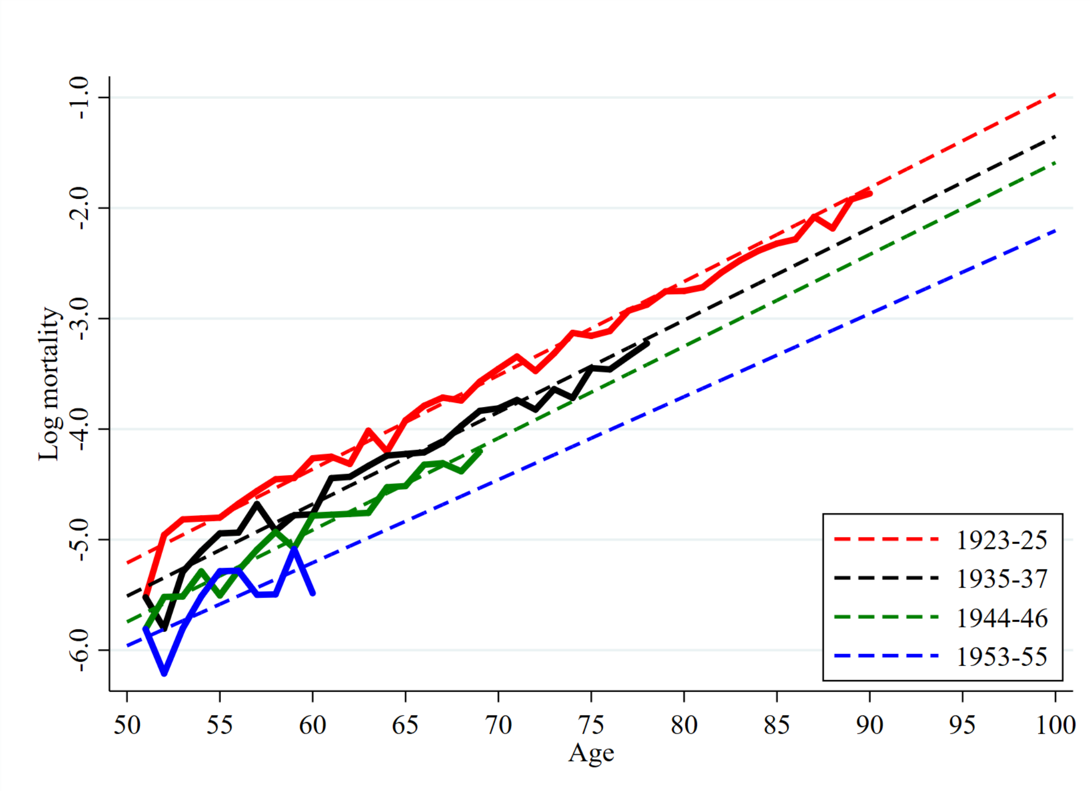
Note: Data are from the OCA administrative file of the Canada Pension Plan. Each line shows the proportion of the sample in the earnings database that survived to age 67 but did not appear in the benefits database. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Each line for men and women shows those born in different decades as indicated. Shaded area indicates the 95 percent confidence interval.

of birth and age 45-49 earnings ventile. For men, the problem recedes quickly after the 5th ventile while for women it fades more slowly. The incidence falls by half between the 1920s and 1930s. Not shown here are those born in the 1940s and 1950s for whom the incidence is negligible.

We next examine the impact of the permanent survivors on our survival rates by graphing the age 75 survival rate for samples where we only include those who survived to age 67. This analysis appears in Figure B5. In the 'Earnings and Benefits' sample we look at the survival rates for those who appear in both the earnings database and the benefit database. The baseline sample has anyone appearing in the earnings database. For women, the differences between the Earnings and Benefits and the Baseline samples are negligible. For men, there is a difference of ten percentage points in the lowest ventile for the 1920s. The difference shrinks by the 5th ventile, and is less severe in the 1930s male sample.

B.3 Gompertz projections

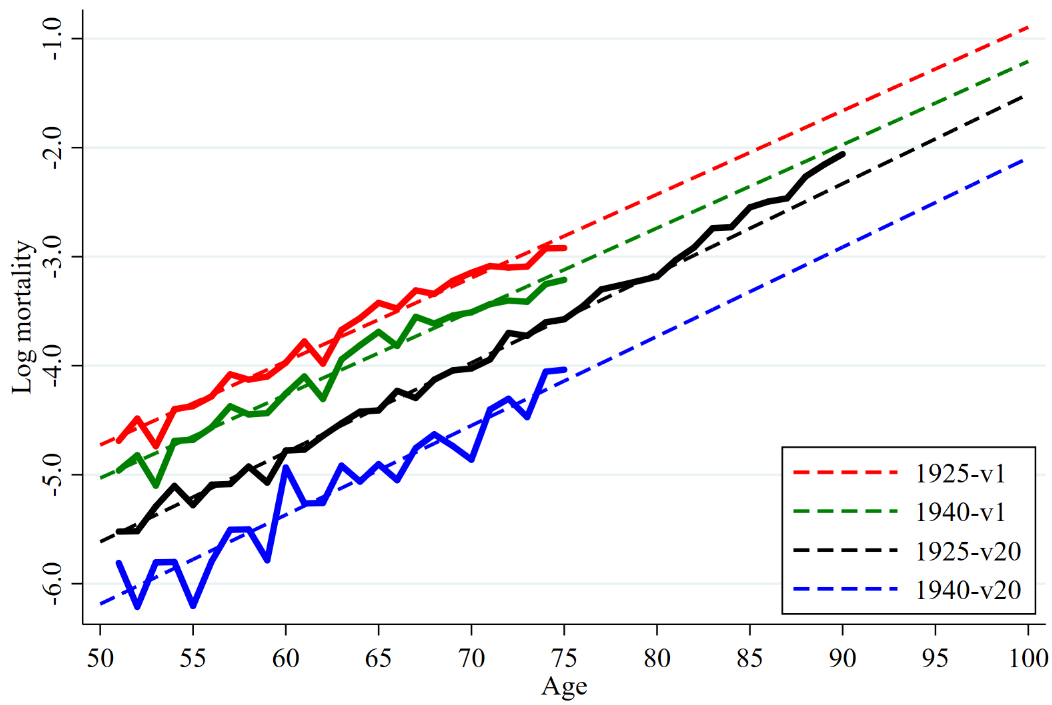
Figure B6: Gompertz Projections for 10th Ventile Males



Note: Data are from the OCA administrative file of the Canada Pension Plan. The solid lines show log mortality in our data for males in the indicated birth cohorts. The dashed lines trace the Gompertz projection.

We project mortality rates for some ages when they are unavailable in the data. The projection makes use of Gompertz Law (see Gompertz, 1825), which asserts that the relationship between age and mortality is log-linear. Here we demonstrate the fit of Gompertz Law to our data and how we adjust the projections. First, in Figure B6 we graph the relationship between age and log mortality by birth year for 10th decile males. The solid lines show the data and the dashed lines are the regression-imputed projections. For the 1923-1925 birth cohort we have data up to age 90, and the fit is very tight. For the 1953-1955 birth cohort we only have data up to age 60, leaving the projection more variable.

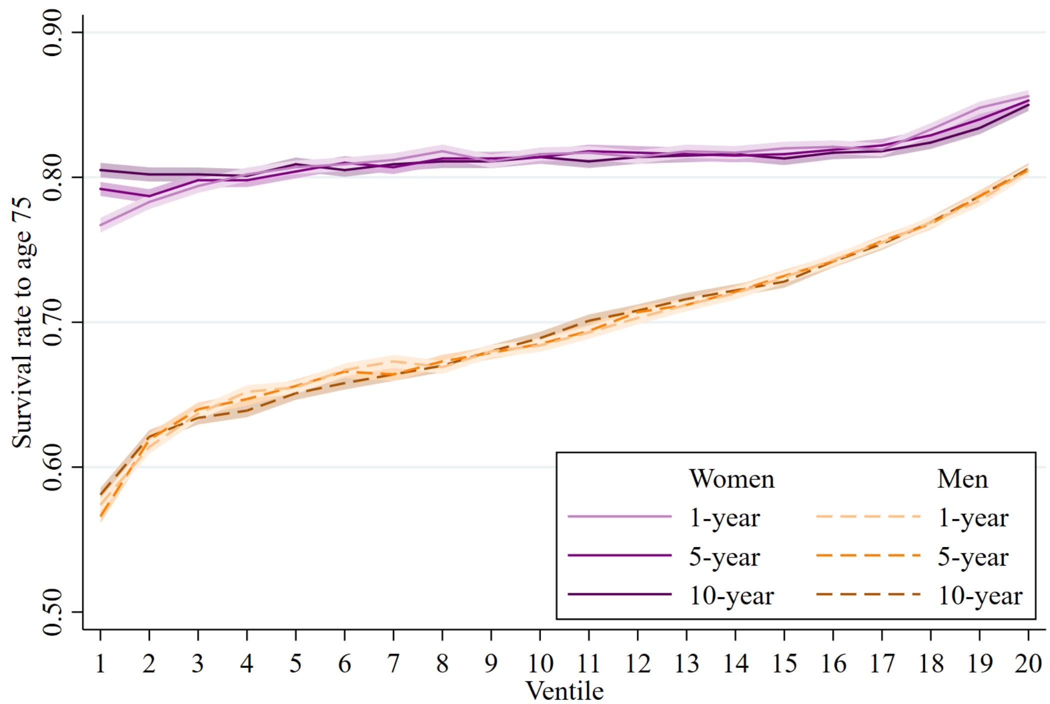
Figure B7: Gompertz Projections for 1st and 20th Ventile Males



Note: Data are from the OCA administrative file of the Canada Pension Plan. The solid lines show log mortality in our data for males in the indicated birth cohorts. The dashed lines trace the Gompertz projection.

In the next graph, Figure B7 shows the results for different birth cohorts for males at ventile 1 and ventile 20. We use data only up to age 75 to make the projections. The Gompertz projections appear to perform well for the 1940 birth cohort. For the 1925 birth cohorts, the data begins to depart from the Gompertz projection after age 75. Investigating this across birth cohorts reveals this is related to the Permanent Survivors issue discussed above, mostly affecting male low-ventiles in the 1920s.

Figure C1: Age 75 Survival for Different Earnings-Averaging Periods



Note: Data are from the OCA administrative file of the Canada Pension Plan. The three lines for men and women show age 75 survival for different sorts into ventiles. The three sorts are based on average earnings in the indicated time period windows. Shaded area indicates the 95 percent confidence interval.

C Appendix: Measurement of lifetime earnings

C.1 Averaging period

Our main results are based on average income between the ages of 45 and 49. Here, we investigate the sensitivity of our results to changing this averaging window. In Figure C1 we plot the age 75 survival for 1930s-born men and women using three different averaging windows: one year (age 49), five years (age 45-49) and ten years (age 40-49).[30] In all cases we impose the same earnings requirement of four years of positive earnings between the ages of 45 and 49 in order to maintain a consistent sample. The results show very little sensitivity to the averaging window.

The lack of sensitivity relates to the mobility of individuals within their cohort earnings distribution

[30]See Cristia (2007) for a comparison of different averaging periods using U.S. data.

as they age. To look deeper, we examined a sample of men in the fifth decile of the 1953-55 cohort's earnings distribution based on age 45-49 average earnings, and then examined what deciles they belonged to based on their average earnings at age 35-39 and age 40-44. The resulting cross-tabulations are provided in Table C1. While there appears to be considerable mobility in the cohort-based earnings distribution, a large portion of individuals remain in the same decile as they age. Of those in the fifth decile based on age 45-49 earnings, nearly one third were in the 5th decile based on age 40-44 earnings and 22 percent were in the 5th decile based on age 35-39 earnings. Moving far away from the fifth decile (to the first or ninth-tenth deciles) is quite rare.

Table C1: Distribution of Age 45-49 Fifth Decile Earners at Earlier Ages

Decile	at age 40-44									
at age 35-39	1	2	3	4	5	6	7	8	9–10	Total
1	850	605	545	370	185	45	20	10	5	2635
2	200	480	765	750	495	145	55	25	10	2920
3	140	405	945	1465	1155	415	105	30	20	4685
4	115	255	750	1870	2490	835	215	80	20	6630
5	55	165	490	1390	5480	2160	335	100	40	10220
6	35	100	265	600	3545	4855	620	135	55	10205
7	20	70	145	330	725	1830	900	265	80	4365
8	20	35	90	160	265	435	525	380	165	2070
9–10	25	30	75	120	170	215	290	360	735	2025
Total	1455	2145	4065	7050	14510	10935	3065	1380	1135	45750

Note: Data are from the OCA administrative file of the Canada Pension Plan.

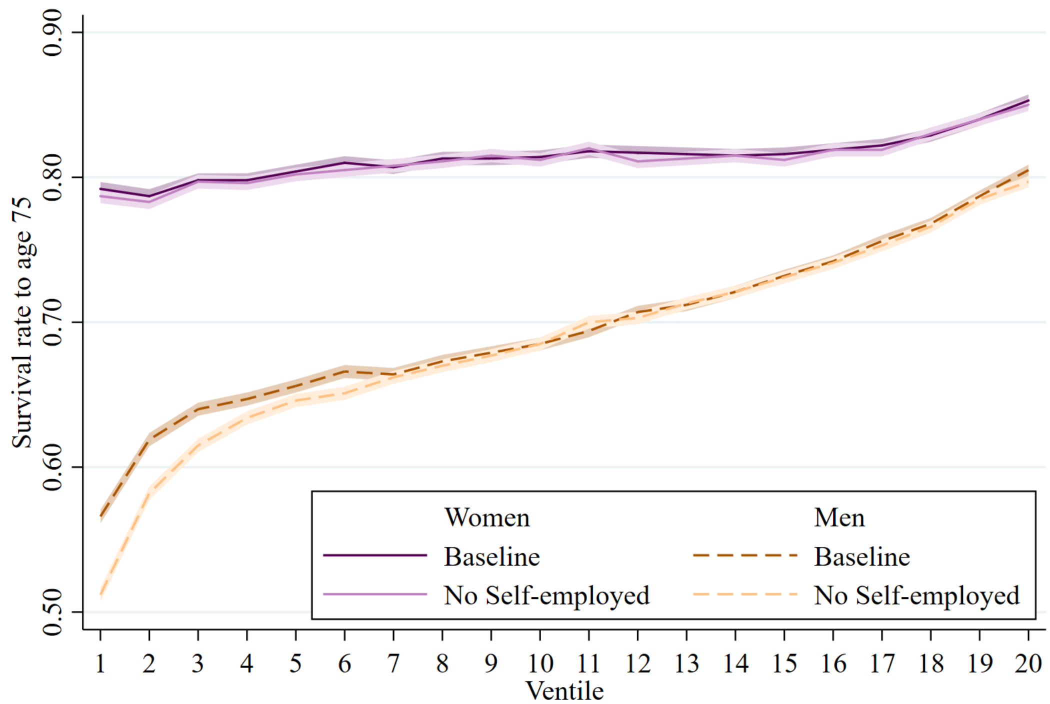
Chetty et al. (2016) use a one-year family income measure to index families in their analysis. Our results here lend support to their assumption that mid-life income is stable enough to support using only a one-year averaging window to examine the income-mortality relationship.

D Appendix: Additional results

D.1 Self-employment

Our data reports income earned through employment and through self-employment for each year, which we sum for our definition of annual earnings. To assess the sensitivity of our results to this

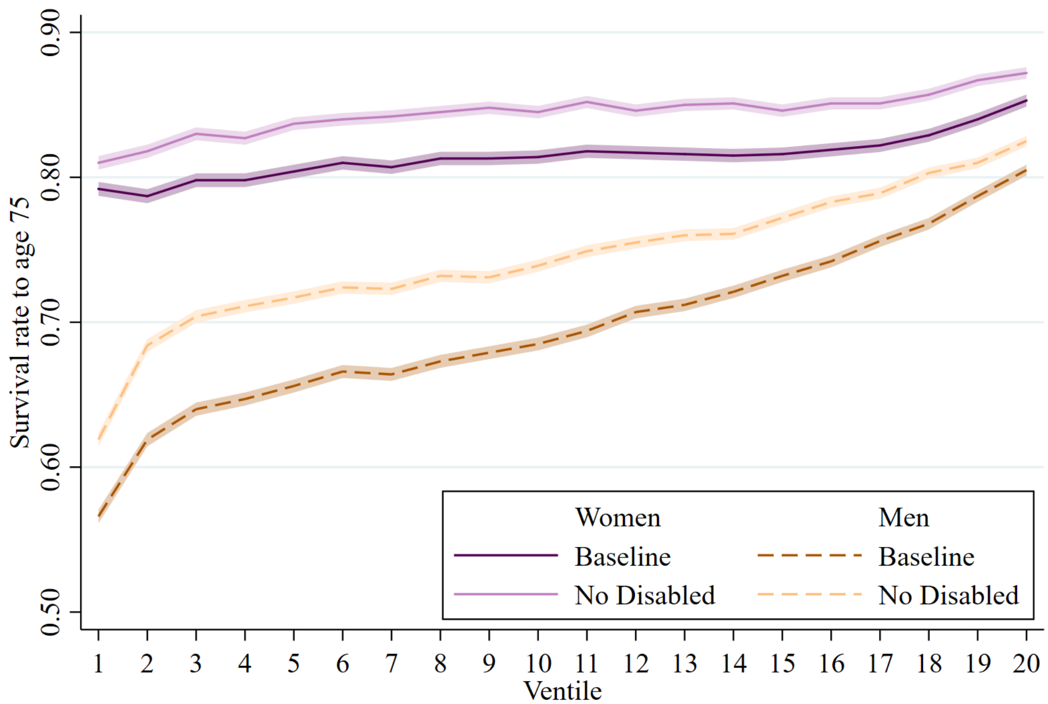
Figure D1: Age 75 Survival for Samples without Self-Employed Individuals



Note: Data are from the OCA administrative file of the Canada Pension Plan. The 'No Self-Employed' sample excludes those with any years of self-employment income, while the baseline sample does not. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Shaded areas indicate 95 percent confidence intervals.

choice, we graph in Figure D1 the age 75 survival rate for men and women for our baseline sample and a sample which excludes anyone with self-employment income in any year. We show the results by ventile assigned by average earnings from age 45-49. The figure uses all Canadians born in the 1930s. The survival rates for women are indistinguishable, while for men survival rates below the 8th ventile are higher in our baseline sample than the sample that excludes the self-employed, suggesting that the self-employed at lower earnings ranges have higher mortality rates than those with employment earnings.

Figure D2: Age 75 Survival for Samples without Individuals who have claimed Disability Benefits



Note: Data are from the OCA administrative file of the Canada Pension Plan. The 'No Disabled' sample excludes those who ever claimed disability benefits, while the baseline sample does not. Earnings ventiles are characterized by the average earnings observed between ages 45-49. Those born in 1930s included here. Shaded areas indicate 95 percent confidence intervals.

D.2 Disability

We can observe whether someone claimed disability benefits through the Canada Pension Plan. At age 65, disability benefit recipients are converted to retirement benefits, so we can observe deaths that occur during receipt of either of these benefits. In our main sample we include those who go through disability benefit receipt. In Figure D2 we show the age 75 survival rates for men and women in our baseline sample and a sample which excludes those who were on disability benefits at any time. We categorize earnings based on the age 45-49 average using Canadians born in the 1930s and plot the proportion surviving to age 75 for each ventile for men and women. The results show a substantial gap between the baseline and the 'no disabled' sample, reflecting a lower survival rate for those who were at some point collecting disability benefits.

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