The evolution of longevity: Evidence from Canada

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Abstract. Canadian men in the top earnings ventile live eight years (11%) longer than do men in the bottom ventile. For women, the difference is 3.6 years. This earnings–longevity gradient has shifted uniformly across earnings groups through time, in stark contrast to in the US. We demonstrate that the widely used period measurement method can differ from cohort measures. For middle-aged men, we find a recent slowdown of mortality improvements, echoing the situation in the US. With comparable data, the Canadian earnings–longevity gradient is half the US gradient; but one quarter of this gap may result from Canada–US earnings differences.

Résumé. Évolution de la longévité: l'exemple du Canada. En matière de revenus, les hommes au Canada situés dans le vingtile supérieur vivent huit ans (11%) de plus que les hommes situés le vingtile inférieur. Pour les femmes, la différence est de 3,6 ans. Ce gradient revenus/longévité n'a cessé d'évoluer uniformément dans le temps et pour toutes les catégories de revenus, en net contraste avec les États-Unis. Nous montrons que la méthode de mesure par période, largement utilisée, peut différer de la mesure par cohorte. Pour les hommes d'âge moyen, nous constatons un ralentissement récent de l'amélioration de la longévité comparable à celui observé aux États-Unis. À l'aide de données comparables, il apparaît que le gradient revenus/longévité est moitié moindre

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pour le Canada que pour les États-Unis; néanmoins, un quart de cet écart découle des disparités de revenus entre les deux pays.

JEL classification: I14, J11, J14

1. Introduction

Evolving patterns of longevity present significant challenges for pension and health insurance programs around the world and are also a fundamental dimension of social inequality. The recent findings of Chetty et al. (2016) provide evidence of lower mortality among those with higher incomes in the United States, with recent increases in life expectancy favouring those with higher incomes. These findings resonate with a long line of research showing a growing gap across socio-economic status in longevity in the United States; however, the forces driving the growing gap are not yet well understood. Cutler (2019) calls for more international comparative evidence to improve understanding.

In this paper, we study the evolution of longevity in Canada to advance understanding of the social and economic forces that drive longevity. We utilize 50 years of administrative public pension data to examine survival to older ages across quantiles defined by a measure of individual mid-career earnings, looking at changes across 30 years of birth cohorts and 50 years of observed mortality. These data allow us to compare our results to recent findings in the United States in order to emphasize ways in which Canadian longevity is similar to and different from the United States. This comparison between two neighbouring countries provides some context in which we can consider different factors potentially underlying the longevity gradient.

We have several important findings. First, despite a relatively generous social safety net and access to health insurance, there exists substantial differences in life expectancy across the earnings distribution in Canada. Over the time period of our sample, men in the top 5% of the earnings distribution lived eight years longer than those in the bottom 5% after age 50, a difference of 11% of a lifespan. Second, across 30 years of birth cohorts, longevity in Canada has shifted almost uniformly for men along the whole 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 in the top half of the income distribution. Third, we show that these shifts in longevity through time are much larger than can be explained by differences in income alone, strongly suggesting that factors other than income underlie longevity improvements. Fourth, we explore the importance of methodological differences between our cohort-based approach to estimating mortality and life expectancy and widely used approaches for measuring period life expectancy. In the Canadian context, we find the period life expectancy approach to understate the steepness of the earnings–longevity gradient. Finally, we make some direct comparisons to recent evidence from the United States. We compare our results to those of Chetty et al. (2016) using a similar methodology and find longevity gradients for the top half of the earnings distribution have similar slopes in the two countries. However, the longevity gradient for the bottom half of the distribution is significantly flatter in Canada than in the United States. Overall, the earnings–longevity gradient in Canada is about half the US gradient; but earnings differences between Canada and the United States can explain about one quarter of this gap. We also find that mortality improvements for Canadian men 50 to 60 years old stopped for recent cohorts, but they do not worsen as was found for the United States for non-Hispanic white men by Case and Deaton (2015).

In the next section, we begin by discussing related research to put our work in context. We then describe our dataset and empirical methods. Next we present our main results describing the Canadian longevity gradient. We then compare estimates based on standard period methods for estimating mortality and life expectancy to our cohort-based estimates, followed by comparisons of our results to recent US research. We conclude with a discussion of the potential explanations and implications of our findings.

2. Related research

Research on the relationship between socio-economic status and mortality has employed both survey-based data and administrative data. We organize our discussion of existing evidence along these lines, with a closing argument explaining how our work contributes to this literature.

The seminal empirical work of Kitagawa and Hauser (1973) studied socio-economic status and mortality by merging death records onto the 1960 US 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 on the gradients between socio-economic status and mortality. National Academies of Sciences, Engineering, and Medicine (2015) and Auerbach et al. (2017) use the Health and Retirement Study, Meara et al. (2008) use the Current Population Survey, while Cristia (2007), Attanasio and Hoynes (2000) and Bosworth et al. (2016) use the Survey of Income and Program 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 US at younger ages driven by diminishing gaps with more disadvantaged children.

In Canada, census records have been matched directly with mortality records looking at socio-economic inequalities (Tjepkema et al. 2013), mortality after unemployment (Mustard et al. 2013), income inequality in sub-regions (Ross et al. 2000) and specifically at the province of Manitoba (Mustard et al. 1997). 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. (2019) apply the Currie and Schwandt (2016) ranking methodology to Canada, finding decreases in socio-economic gradients at younger ages.

Surveys offer the advantage that researchers can look at varied dimensions of socio-economic status, including income, wealth, race, marital status and education. Surveys may also provide information about health behaviours, allowing researchers to uncover the mechanisms that drive health outcomes. For example, Cutler et al. (2011) used survey data to study changes over time in US education–mortality gradients and determine the role of risk factors like smoking and obesity. Health behaviours and mortality are studied using the National Population Health Survey in Canada by Orpana et al. (2010). While surveys do enrich the breadth of factors that can be included in the analysis, the smaller sample sizes and compressed time coverage of most surveys limits the ability of researchers to address fundamental long-run questions.

Administrative data, while lacking in covariates, often afford larger sample sizes and may permit longer-run analysis.[1] In Canada, Wolfson et al. (1993) used pension administrative data, studying earnings gradients of mortality for early cohorts of Canada Pension Plan (CPP) 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 CPP started covering earnings only in 1966. This limited both the cross-cohort comparisons and the analysis of older-age mortality. Office of the Chief Actuary (2015) also uses CPP administrative data, looking at mortality patterns of those over age 65 by CPP benefit levels. Since CPP benefits cover only earnings below a cap set near median annual earnings, the CPP does not cover earnings in the top half of the earnings distribution. This limits the scope of the Office of the Chief Actuary (2015) study. 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 a selective sample of firms and plan participants limits their analysis.

In the United States, Waldron (2007) uses Social Security records spanning 1912 to 1941, finding that improvements in mortality were concentrated in the top half of the lifetime earnings distribution. Duggan et al. (2008) also use Social Security administrative records covering the 1900 to 1942 birth cohorts, finding only a small two- to three-year difference in the age of death between the 10th and 90th percentile of lifetime earnings. More recently,

1 The administrative data that has been used to study older-age mortality do not permit a distinction between Indigenous and non-Indigenous peoples' mortality rates. Feir and Akee (2019) find status First Nations mortality rates (under age 65) are substantially higher than the general population in Canada.

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 favour higher earners. A recent study using Norwegian administrative data (Kinge et al. 2019) uses similar methods and also finds steep longevity gradients, with recent gains in life expectancy that favour those with high income.

Our paper contributes to this literature in several ways. First, our administrative data source affords an extraordinary time-span of data and large sample sizes. The time-span of our data permits the use of cohort rather than period analysis. We can use our data to check on key assumptions of important recent papers in this literature and also compare cohort to period 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, or may not, be driving the steepening mortality gradients in the US.

3. Data

We employ administrative records from the CPP, Canada's earnings-related public pension plan covering Canadians outside Quebec.[2] 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, ethnicity, place of residence or immigrant status and 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.

We impose several additional sample conditions which are documented in online appendix A. To summarize, our analysis describes individuals born from 1923 to 1955, who survive to at least the end of the calendar year in which they turn age 50, whose most recent earnings are observed outside the province of Quebec and with positive earnings in at least four of five years between the ages of 45 and 49. The final sample contains 3.7 million men and 2.8 million women.[3]

2 We make use of an existing administrative file known as the "OCA" file, which is prepared for the periodic statutory review of the CPP by Canada's Office of the Chief Actuary.

3 We compare our sample to the population at age 50 in online appendix section A2, which suggests our sample is highly representative of the population.

There are different databases for earnings and for benefits. When someone applies to take up a CPP benefit, a record in the benefits file is originated based on the information in the earnings file.[4] 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.[5] 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. Some early earnings were top-coded, so we impute earnings above the cap using individual information on earnings growth rates in neighbouring uncapped years. Further details and assessment of these imputations are in online appendix section B1. The earnings database reports date of death, including from those who died before 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 start date, date of birth and reported date of death. Those who claimed benefits under Quebec's parallel plan are not included in this benefits database nor are those who have never filed a benefits claim. Non-claiming could arise from not being aware of an entitlement, due to a decision that a small entitlement is not worth the application effort or because the person has left Canada.

People who appear in the earnings database—but whose death is not recorded in the benefits database or elsewhere—represent a non-trivial share for certain cohorts and earnings groups. This matters for our analysis because they appear to be "permanent survivors" as they are not recorded as dying. We performed an extensive analysis of this permanent survivor issue in online appendix section B2, finding that it is largely confined to a few low-earning ventiles in the 1920s birth cohorts. For this reason, as we discuss our results we note cases when the permanent survivors may cloud our inferences.

4. Empirical approach

Our main focus is the relationship between mid-career earnings and longevity. The data span 50 years, allowing us to construct cohort-based measures of longevity, including both raw survival rates and calculated life expectancies.

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4 There is also a separate database for disability benefits, from which we collect death records if the death was missed in the other databases.

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

In this section, we describe the earnings calculation and survival rate measurement in turn.

To proxy for mid-career earnings, we take the sum of reported employment and self-employment earnings and construct an inflation-adjusted average between ages 45 and 49. We impose a requirement of positive earnings in at least four of those five years. This choice minimizes the impact of "permanent survivors," people who have sporadic earnings and those who do not ever show up in the benefits database. Online appendix section C1 provides sensitivity analysis on this five-year window, showing little difference in survival probabilities when we sort our sample using a one-, five- or 10-year window for average earnings. Separately for men and women for each birth cohort, 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.

We use both survival rates and life expectancies for our analysis, since each gives a different view into changes in inequality.[6] However, both measures are based on the same raw survival rates observed from our data that we reshape as follows.

We aim to calculate survival rates for ages 51 to 100 conditional on survival to age 50. These survival rates will be used on their own, and also to form our life expectancy measure. We use December 31 of each year to measure age and estimate survival rates by age for each year of birth, sex and earnings quantile. With data from 1966 to 2015, we can observe survival directly in our data from age 50 up to age 90 for the 1925 birth cohort but only up to age 60 for the 1955 birth cohort. To fill in missing survival rates, we make projections based on Gompertz's Law (see Gompertz 1825). Gompertz's 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.[7]

To form our complete block of survival rates (ages 51 to 100 for all birth 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 (for cohorts born after 1940). Next, we use Gompertz projections based on available data from ages 50 to 75 to form survival rates for ages up to 89. Third, we use

6 Absolute changes in raw survival rates can yield different inequality patterns than proportional changes since the baseline risk varies across earnings groups.

7 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 under predict mortality.

population longevity data for ages 90 plus.[8] 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. We provide more detail and evaluate the fit of the Gompertz projections in online appendix B3. In our discussion of results in the next section, we place an emphasis on life expectancy estimates representing earlier birth cohorts for which we are able to observe mortality up to age 75. While we present some life expectancy results for cohorts born in the 1950s, the estimates will have larger confidence intervals. This results from our limited ability to observe mortality at older ages, which means our Gompertz projections have a more-restricted base leading to more variable projections.

5. Main results

The presentation of results begins with basic survival rates by sex, cohort and earnings quantile. We then characterize the changes in projected life expectancy across cohorts and earnings quantiles. Finally, we consider how changes in earnings over time relate to shifts in longevity across birth cohorts.

5.1. Survival rates by quantile

We focus first on survival rates since they constitute the most basic component observed directly in our data and do not rely on the Gompertz projections discussed in the previous sections. In the analysis that follows, these survival rates are aggregated and projected to form life expectancies. But to begin, in figure 1, we examine survival rates to age 75 by percentile of ages 45 to 49 earnings for those born in the 1930s and who were alive at age 50. There are separate lines for women and for men, with a 95% confidence interval indicated for each line by shading.

Figure 1 shows three clear results. First, for men there is a strong survival gradient with earnings, but a more modest 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.[9] In our sample, the more modest 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 between the first and 10th percentile of 11 percentage points for men. Third, between the 10th and 100th percentile, the rise in

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

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

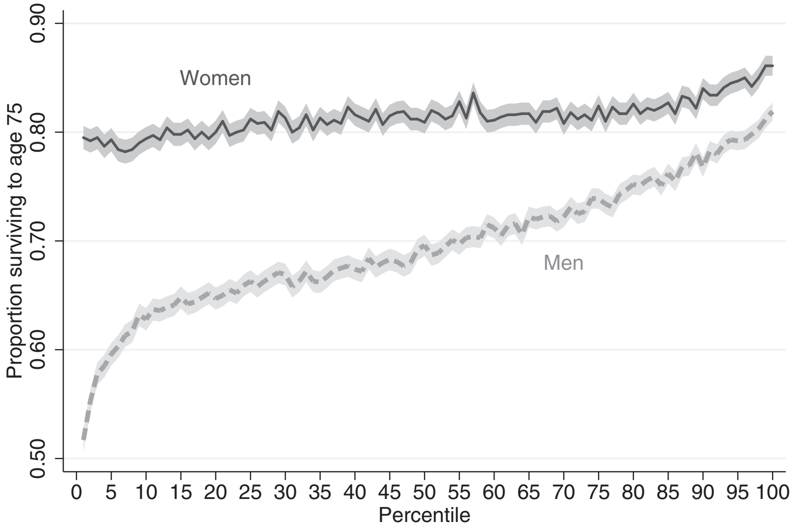

FIGURE 1 Survival to age 75, by earnings percentile
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. Earnings percentiles are characterized by the average earnings observed between ages 45 and 49. Those born in the 1930s are included here. Sample includes only those who survived to age 50. The shaded areas indicate the extent of the 95% confidence intervals.

age 75 survival is close to linear, going from 63% to 82%. This almost-linear consistency of the gradient over much of the earnings distribution provides further evidence against the "hardship threshold" hypothesis (which suggests no further longevity gains above some threshold) that was studied and rejected in Wolfson et al. (1993) and Waldron (2013). There are continued gains in survivorship as earnings increases.

We now proceed to an 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 (as described in online appendix B3). The variability of our life expectancy projections changes across cohorts, driven by two factors. On the one hand, we have more observations for later cohorts, which pushes the variability down. On the other, our Gompertz regressions have fewer available ages on which to base the projections for younger cohorts. For example, we can use data only up to age 60 for a birth in 1955. This short span of survivor data for more recent cohorts leads to larger variability in the projections. We have the full range of mortality rates over ages 51 to 75 for the Gompertz regressions for all cohorts from 1940 and earlier. For cohorts born in the 1950s, our projected life expectancies are more variable.

In the discussion of the results, we therefore make use of simulated confidence intervals for inferences about our life expectancy projections.[10]

We begin with an analysis of those born in the 1940s and then compare to those born in the 1920s.[11] These cohorts show less variability compared to later cohorts, so inferences can be made with greater confidence. We extend 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% confidence interval indicated. The figure reveals important results for both 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 difference in life expectancy for those born in the 1940s is 4.3 years, while for men it is 8.9 years. Both of these differences are statistically significant at the 95% confidence level. Living 8.9 years longer is an increase of nearly one third in the post-age 50 lifespan, compared to the 27.8 years of life for men in the first ventile and an 11.4% increase in the overall life expectancy compared to the base of 77.8 years for first-ventile men. For women, 4.3 years is a 13% increase in life after age 50 and a 5% overall increase in lifespan.

We now turn to an analysis of the shifts in this earnings–longevity gradient through time. Comparing those born in the 1920s to the 1940s in figure 2, the shift in life expectancies is mostly uniform across ventiles for women and men. The shifts for women in the bottom five ventiles (and the 11th) are not statistically significant, but the shifts attain significance at the 95% level at other ventiles. For men, the shift between the 1920s and 1940s in figure 2 is significant for all ventiles and features an average increase of 4.4 years.[12]

To look at these data from another angle, we present in figure 3 the same analysis but now display the gains across all cohorts for selected earnings

10 To form the confidence intervals, we do 1,000 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 simulated life expectancy distribution. Our simulated confidence intervals are not necessarily symmetric since the use of invariant population average mortality from age 90 limits the variability of life expectancy calculation when there are low draws on mortality rates.

11 Our 1920s data incorporate 1923–1929 births while the 1940s data incorporate 1940–1949 births.

12 The shift is 2.3 years for the first ventile, much lower than the other ventiles. This reflects, in part, the permanent survivor phenomenon we explore in online apppendix B2 that affects in particular 1920s cohorts in the lowest earnings ventiles.

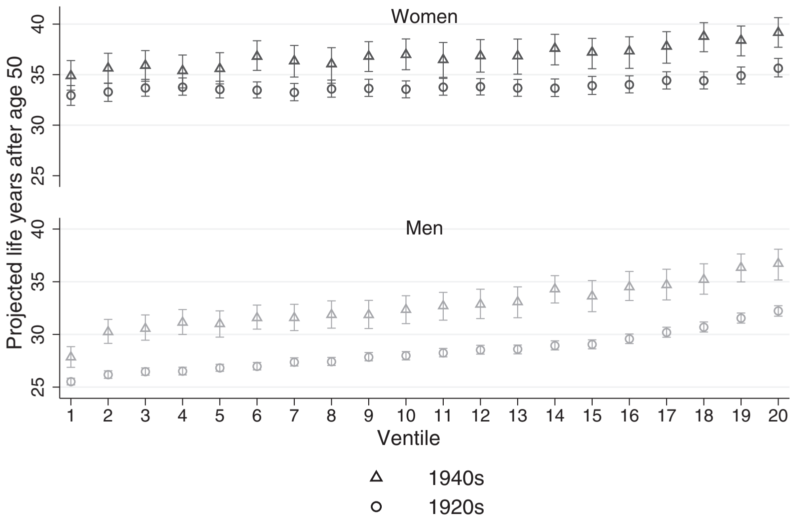

FIGURE 2 Life expectancy from age 50, by ventile and cohort
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. Earnings ventiles are characterized by the average earnings observed between ages 45 and 49. Sample includes only those who survived to age 50. The point estimate is indicated by the marker; the lines show the extent of the simulated 95% confidence interval.

ventiles for women and men separately. The birth cohorts are grouped in threes so that, for example, the "1925" data point has data for the 1923–1925 birth cohort. This depiction provides two main insights. First, the increases in longevity across cohorts are mostly linear and the gap between ventiles fairly constant, especially for men. If the gains had been concentrated in certain cohorts or ventiles instead, the case for interpreting the increase as driven by a distinct policy or social change affecting only some cohorts would be easier to make. Second, the graph reinforces previously made caveats about inferences. The confidence intervals using ventile data for 1950s cohorts are very large in figure 3, and the impact of the permanent survivor issue in the 1920s cohorts for low-earning ventiles can be seen in the flat gains until the 1930s for the first ventile.

To characterize more generally the relationships described in this section, we estimated regressions of life expectancy and survival rates on indicators for birth cohorts and earnings ventiles (with results presented in online appendix D1). This allows us to state the average top–bottom difference after adjusting for cohort effects. The results suggest the average top-to-bottom ventile gradient of life expectancy is 3.6 years for women and 8.1 years for men. The results for survival to age 75 suggest 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 levels.

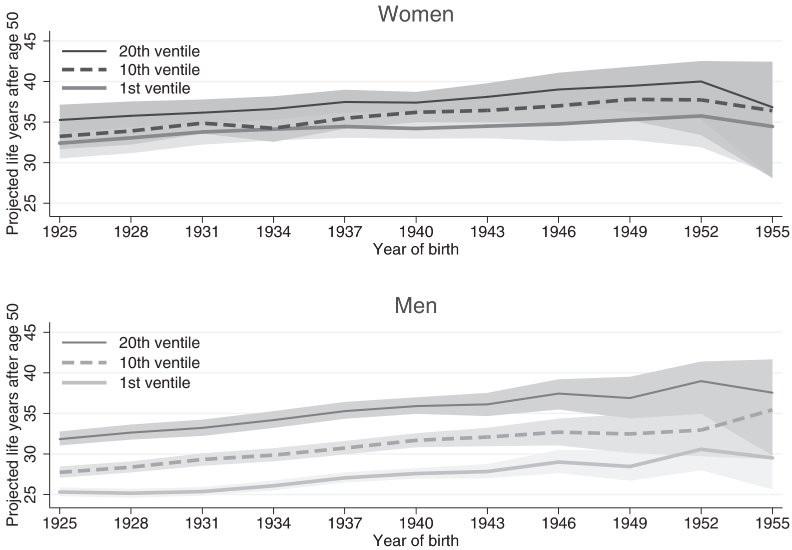

FIGURE 3 Life expectancy from age 50 by cohort and ventile
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. Earnings ventiles are characterized by the average earnings observed between ages 45 to 49. Sample includes only those who survived to age 50. The line connects the point estimates by cohort and the shading indicates the simulated 95% confidence interval.

5.3. Controlling for earnings differences

How much of these gains in longevity across birth cohorts are driven by earnings differences across cohorts? Consider that, among men born in 1923 to 1925, average earnings between ages 45 and 49 for those in the 10th ventile of their distribution were $48,800 (in 2015 Canadian dollars). For men born in 1938 to 1940, average earnings in the 10th ventile were 17% higher, at $56,900. Moreover, earnings did not increase uniformly between birth cohorts. Between the 1923–1925 and 1938–1940 cohorts of men, average earnings in the lower four ventiles and the top ventile decreased slightly while earnings in other ventiles increased. As such, comparisons between the birth cohorts at each ventile (as in figure 2) are comparing individuals with different levels of earnings.

In figure 4, we compare the life expectancy of men in the 1923–1925 and 1938–1940 birth cohorts across the level of average earnings for each ventile.[13] If earnings growth across birth cohorts were driving the longevity improvements, we would not see large differences in life expectancy at the same level of earnings. However, this is clearly not the case. Comparing life

13 We thank a reviewer for suggesting this way of presenting our information, closely following the example of Kinge et al. (2019).

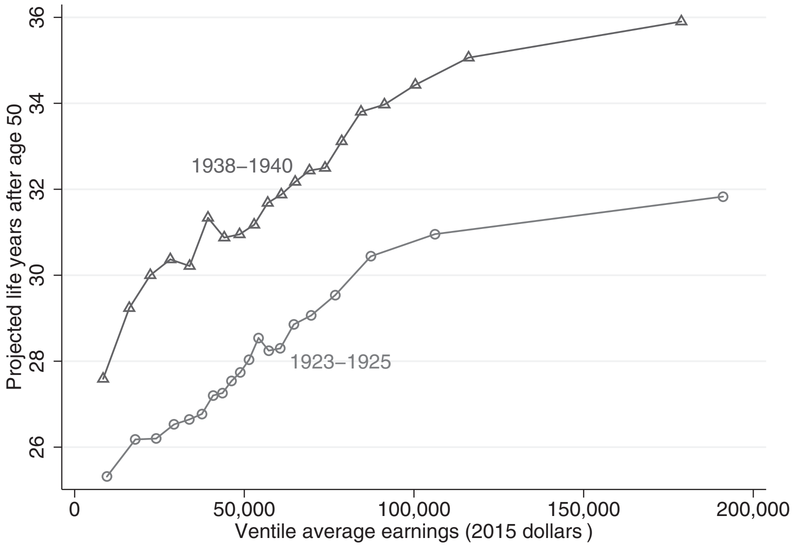

FIGURE 4 Male life expectancy and earnings
NOTES: Data for Canada are from the OCA administrative file of the Canada Pension Plan. Ventile average earnings is the average of our mid-career earnings measure within each ventile.

expectancy across cohorts at the same level of earnings, differences are clearly large and only slightly smaller than when comparing across ventiles. This strongly suggests that the cross-cohort improvements in longevity seen in figure 2 are not driven primarily by improvements in earnings but instead by other factors. We take up the discussion of other potential factors in section 8.

5.4. Summary of main results

In this section, we have presented three main results. First, we documented the existence and magnitude of survival and life expectancy gradients across the earnings distribution for Canada. Our summary findings of an 8.1-year difference between high and low earning men and 3.6 years for women are large and statistically 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 data. Second, we have shown that longevity has evolved with a uniform shift across the earnings distribution in stark 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, 2013). Third, by examining life expectancy across earnings levels within ventiles, we showed that earnings growth was not the driving factor in longevity improvements across birth cohorts.

6. Cohort and period life expectancy

Measures of mortality, survival and life expectancy are commonly based on period methods. With period methods, in any given year, the observed deaths are compared to population at risk and then aggregated cross-sectionally across ages in a given period (typically a year) to form survival rates and estimates of period life expectancy. As such, the mortality rates of individuals in older cohorts will be used to approximate the future mortality of a younger cohort. Period methods are prominent in the recent literature on income gradients and mortality (Chetty et al. 2016, Kreiner et al. 2018 and Kinge et al. 2019).

Period life expectancy is a useful measure if we want to compare general trends in mortality over time. For many questions, though, more precise measures based on the actual lifetime experience of cohorts would be superior if available. We often want to know how social or economic forces have changed the life trajectories of those affected by shocks or to project forward demographic trends. Cohort-based measures are necessary for such analysis. Cohort-based measures require both longitudinal capturing of data and very long time periods, both of which present often-insuperable challenges. This leads to widespread use of period methods by both national statistics agencies calculating life expectancies and researchers. A better understanding of the efficacy of period methods as an easier-to-calculate proxy for cohort survival rates would provide stronger support for their use, particularly in the current context wherein we are aligning earnings and mortality.[14]

Because of the depth of our longitudinal data, we are able to provide in this section some of the first evidence on the comparability of period- and cohort-based measures.

To form period longevity estimates from our data, we follow the methods of Chetty et al. (2016). We form age 51 to 100 blocks of survival rates for each year, sex and quantile of earnings.[15] We use the observed mortality rates up to age 75 to form our Gompertz projections of mortality to age 89 and use population mortality tables for mortality rates at age 90 and over (see

14 It is also important to consider the results of Kreiner et al. (2018), who find that using a measure of income at a single age, rather than more comprehensive lifetime income measures, creates an upward bias in the gradient for period life expectancy. We do not have the same concerns with our measures of cohort life expectancy as earnings are measured mid-career and then allowed to change over time without re-sorting our sample with respect to earnings quantiles.

15 We depart from the methods in Chetty et al. (2016) in several ways. We continue to use earnings rather than family income to characterize the income distribution because our data do not include non-earning sources of income. We do not construct race-adjusted measures of life expectancy. Also, Chetty et al. (2016) use a trapezoidal rule for estimating life expectancy, while we have summed survival rates after reaching age 50.

online appendix B3). We use earnings lagged two years to assign individuals to quantiles. Because we have data stretching back to 1966, we can implement the methodology over almost the entire 50 years of our data. For our purposes here, we calculate life expectancy using data from each decade (1970s to 2010s) separately.

In figure 5, we show the life expectancy for men by ventile using the 1930s birth cohort and the 2000s period life expectancy methods. (Those born in the 1930s were in their 70s during the 2000s, which makes for a reasonable comparison given the age range in our analysis).[16] We focus here exclusively on men since differential selection of women over time complicates the comparisons. Figure 5 shows the methods deliver statistically significant point-wise differences up to the fifth ventile. When considered over the whole range at once, there is strong and significant evidence that the cohort-based gradient is steeper than with the period approach. The difference in slope is 0.09 years per ventile, which adds to 1.7 years over the 20 ventiles.[17] So, the cohort-based slope is 27% steeper than the period slope.

Why is there a difference between cohort and period life expectancy gradients? The main factor lies in how individuals are sorted into earnings quantiles and the impact of transitory income changes on this sorting for period methods. When forming our cohort-based estimates, we rely on earnings at ages 45 to 49 when sorting individuals into quantiles and observe their survival to each age over 50. If they have no earnings at older ages, they remain within our sample and their deaths will be accounted for in our mortality rates. With period methods, individuals at each age are sorted into quantiles according to their recent earnings. Those with no earnings are excluded from the sample. For example, consider that, if someone from a lower quantile at ages 45 to 49 becomes disabled at age 55, they would be excluded from a sample of earners at age 58. Their deaths would not be accounted for in the mortality estimates, resulting in an underestimate of mortality and overestimate of life expectancy. The difference in gradients that we see in figure 5 then suggests period methods may tend to drop individuals from the lower quantiles of mid-career earnings.

We next look to see if our "uniform" shift result from figure 2 can be replicated using period life expectancy methods. Is our finding of a uniform shift specific to the cohort-based method, or can a period-based analysis reveal a similar pattern? The results for the 1970s and 2010s are shown in figure 6. There is a clear upward shift across the decades and this shift is fairly similar

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16 While this choice of comparison years and cohorts is arbitrary, a more complete analysis using a particular cohort and year ranges may provide more direct comparisons—although some precision is lost using data from one cohort alone. We leave this to future work.

17 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 -0.087 (0.031).

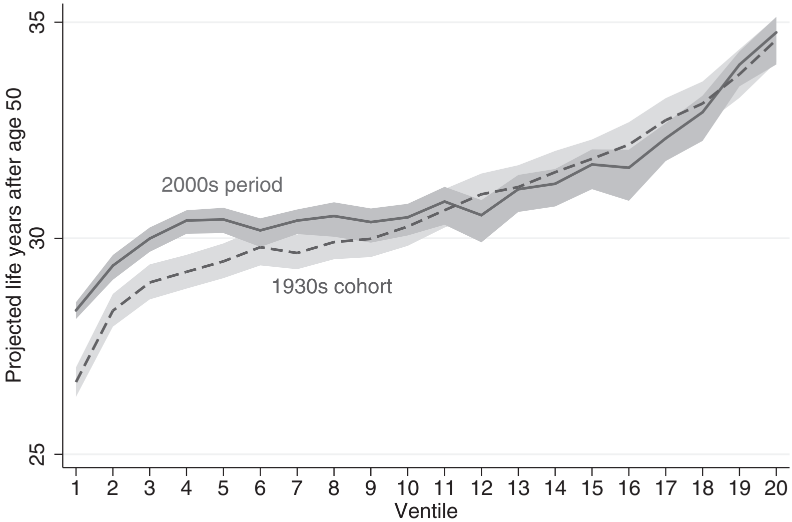

FIGURE 5 Life expectancy using different methodologies
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. The lines here show life expectancy conditional on survival to age 50. The solid line shows longevity in the 2000s using the period life expectancy methods. The dashed line shows the cohort-based method for those born in the 1930s. Shaded areas show simulated 95% confidence intervals.

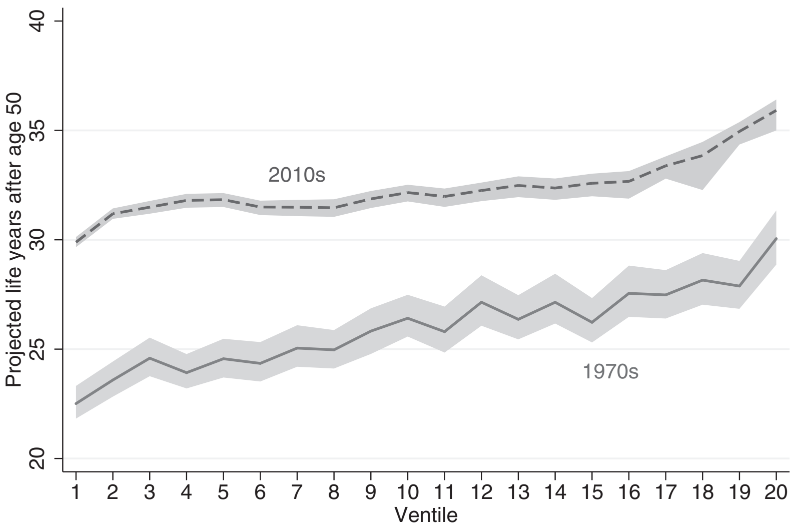

FIGURE 6 Life expectancy across decades using period methods
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. The lines here show life expectancy conditional on survival to age 50. Both lines show results using the period life expectancy methodology. Shaded areas show simulated 95% confidence intervals.

across earnings ventiles. The gain at the first ventile is 7.4 years, while at the 20th ventile it is 5.9 years. This demonstrates that our uniform shift result can be replicated in this Canadian case using either cohort or period methods.

Our results here have important implications for research and population analyses using the more easily implemented period methods. Our results indicate that the slope of the earnings gradient is likely steeper in cohort-based calculations and suggest that further investigation of recent US results is warranted, for example to determine if the income gradient results in Chetty et al. (2016) are understated. We have also shown that in the Canadian case the period methods can reproduce the pattern of changes through time that we first showed with cohort-based methods in section 5. Results in other countries may vary, depending on the nature of income mobility and whether mortality is trending up or down in different parts of the income distribution.

7. US comparisons

In this section, we use our data to make direct comparisons to US evidence in four ways. First, we directly compare longevity gains across birth cohorts and earnings quantiles for Canada and the US. Second, we use our data to construct a longevity gradient using the same methodology, time period and ages as Chetty et al. (2016) in order to facilitate a direct comparison of Canada and the US. Third, we re-sort our data based on quantile thresholds derived from the US earnings distribution in order to observe how much of the difference in longevity gradients may be driven by earnings differences across the countries. Finally, we extract a sample of 60-year-old men in order to examine male mortality between ages 50 and 60. This allows us to observe evidence of any reversal in male mid-age mortality as documented by Case and Deaton (2015, 2017).

7.1. Cross-cohort gains

We compare the gains across cohorts from our data to the key findings of National Academies of Sciences, Engineering, and Medicine (2015). We sort into earnings quintiles here, for two reasons. First, it makes our results comparable to the US. Second, the larger sample sizes in the quintile bins make the Gompertz projections for the 1950s cohorts less variable than was observed earlier in figure 3 using ventiles. We present the analysis across all decades and quintiles in table 1.

Looking across the top panels of table 1 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 1 reveals the growth in longevity across cohorts of Canadian women and men. For women, there

TABLE 1
Life expectancy from age 50, by quintile and cohort

Birth cohort	Quintile				
	1	2	3	4	5
			Canada – Women		
1920s	33.5 (33.1, 33.9)	33.5 (33.1, 33.9)	33.7 (33.3, 34.1)	33.8 (33.4, 34.2)	34.8 (34.4, 35.2)
1930s	34.4 (34.1, 34.8)	35.1 (34.8, 35.5)	35.3 (34.9, 35.6)	35.3 (35.0, 35.7)	36.3 (36.0, 36.7)
1940s	35.4 (34.6, 36.2)	36.2 (35.5, 37.0)	36.8 (36.0, 37.6)	37.3 (36.4, 38.0)	38.5 (37.7, 39.2)
1950s	35.0 (32.7, 37.2)	37.5 (35.2, 39.3)	38.6 (36.4,40.1)	37.0 (34.3, 39.0)	38.2 (35.7,40.2)
			Canada – Men		
1920s	26.2 (26.0,26.3)	27.1 (26.9,27.4)	28.2 (28.0,28.4)	29.0 (28.8,29.3)	31.1 (30.9, 31.4)
1930s	28.3 (28.1,28.5)	29.7 (29.5,29.9)	30.5 (30.3, 30.7)	31.7 (31.4, 31.9)	33.6 (33.3, 33.8)
1940s	29.9 (29.3, 30.5)	31.5 (30.9, 32.2)	32.4 (31.8, 33.2)	33.9 (33.2, 34.6)	35.7 (35.0, 36.5)
1950s	30.5 (28.7, 32.2)	32.0 (30.0, 34.0)	33.3 (31.5, 35.3)	33.7 (31.5, 35.8)	36.2 (34.0, 38.1)
			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

NOTES: 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% confidence interval in parentheses reported below. We have all birth years in the 1930s and 1940s. We include 1923 to 1929 for the 1920s and 1950 to 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.

is no clear pattern across quintiles, with the largest gain in the third 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 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.

We make the comparison to the United States in the bottom two panels of table 1, where we reproduce the headline results from National Academies of Sciences, Engineering, and Medicine (2015, p. 3), which compares projected life expectancies conditional on reaching age 50 for Americans born in 1930 with those born in 1960. Between these cohorts of men, there was no growth in American longevity in the bottom two quintiles. In contrast, gains in the

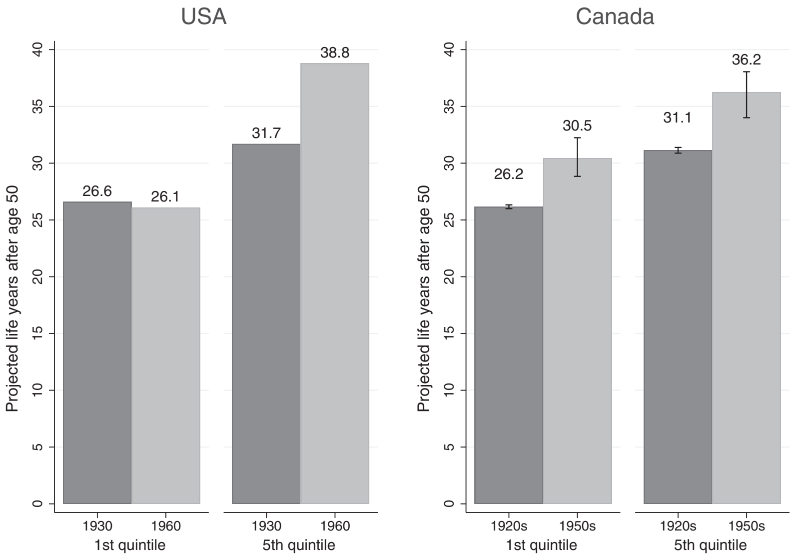

FIGURE 7 Longevity gains for men in United States and Canada
NOTES: Data for Canada are from the OCA administrative file of the Canada Pension Plan and from figure S1 in National Academies of Sciences, Engineering, and Medicine (2015, p. 3) for the United States. Samples include only those who survived to age 50. The first and fifth quintiles are shown for each country.

fifth quintile were projected at 7.1 years. For a comparable 30-year time span, we consider the results from Canada for the first and fifth quintiles between the 1920s and 1950s for men. 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. These results for the US and Canada are summarized for the first and fifth quintiles in figure 7.

7.2. Longevity gradients

The longevity gradients presented in section 5 appear to be much less steep for Canada than gradients in the US. For the period 2001–2014, between the top and bottom ventiles, Chetty et al. (2016) find gradients in life expectancy after age 40 of 7.9 years for women and 11.9 years for men.[18] If we compare these US estimates to our Canadian results in figure 2 of 8.9 years for men and 4.3 years for women, the magnitude of the life expectancy gradient in Canada (after age 50) appears to be about 75% of the value in the United States for men and 54% for women. But there are methodological (cohort vs. period),

18 See figure 2 in Chetty et al. (2016). 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.

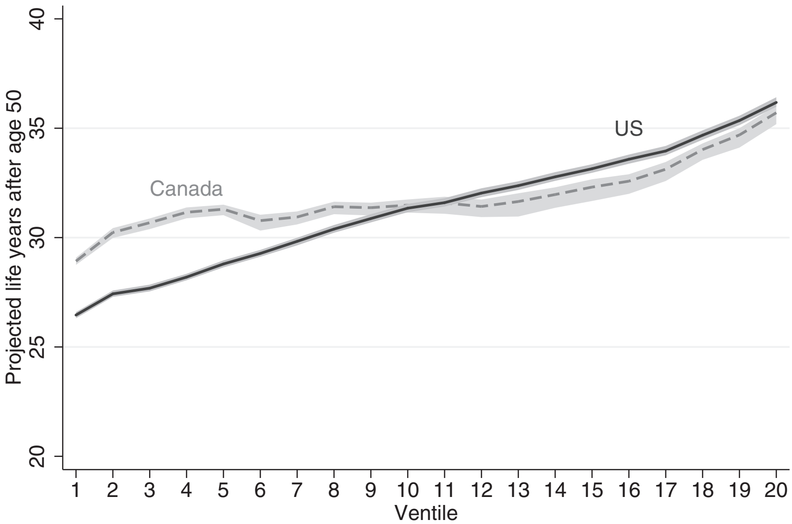

FIGURE 8 Canada and United States period–longevity gradients, 2001–2014
NOTES: Data for Canada are from the OCA administrative file of the Canada Pension Plan. The lines here show life expectancy conditional on survival to age 50. Life expectancy from age 50 for the United States represents the authors, tabulations using mortality rates available in the online table 15 of Chetty et al. (2016). The period methodology of Chetty et al. (2016) for the period 2001–2014 is used for both countries. Shaded areas show simulated 95% confidence intervals.

time period and age differences that potentially cloud those comparisons. Our goal in this section is to present our Canadian results alongside US results using the same methodology, time period and ages.

For the US, we make use of the mortality rates of men provided by Chetty et al. (2016, online appendix table 15) to construct a measure of life expectancy after age 50 that is comparable to our Canadian period life expectancy after age 50 (presented in figure 5).[19] For Canada, we create a period-method dataset spanning the years 2001 to 2014 to match the years covered by Chetty et al. (2016). This aligns our US and Canadian data in methodology, time period and ages.

Our results are presented in figure 8. The longevity gradient is much steeper for the United States than Canada. By fitting a simple linear regression model, we can estimate the Canadian slope and the slope differential for comparison. The Canadian slope is 0.24 years of life expectancy per ventile, while the

19 The mortality rates we use and our measure of life expectancy are not race-adjusted, making them less comparable with results in figure 2 of Chetty et al. (2016). For US mortality rates after age 90, we used population-level mortality rates and only measure life expectancy to age 100 rather than 119 to keep it consistent with our Canadian methodology.

differential is 0.23.[20] So, while the initial comparison made above indicated that the Canadian slope was about 75% of the US slope, our comparison here using common methodology, time period and ages shows the Canadian slope to be about half the US slope. So, putting the two countries on an equal footing makes the Canada–US difference even more stark.

The Canada–US difference in gradient, however, results largely from a difference in the bottom half of the male earnings distribution. For Canada, the difference between the first and 10th ventiles in life expectancy is only 2.5 years but is 4.9 years in the United States. The longevity gradients between the 10th and 20th ventiles are only slightly different, at 4.8 years for the US and 4.3 years for Canada. This highlights the importance of understanding what social, economic or policy differences between the two countries are affecting men in the lower half of the earnings distribution in ways that shape the longevity gradient.

7.3. Earnings differences

The Canada–US difference in longevity gradients could arise from earnings differences. Since the American earnings distribution is more skewed, the top ventile in the United States has a higher threshold for membership than in the Canadian case. So, it is possible these earnings differences contribute to the observed longevity–gradient differences.

We investigate the importance of earnings differences by re-sorting our data using ventile thresholds based on earnings in the United States.[21] The distribution of earnings is clearly wider in the US than in Canada, so membership in the top ventile requires higher absolute earnings levels in the US than in Canada. The consequence of using the higher US thresholds with our Canadian data is that some high-survival Canadian men who were in the top Canadian ventile are now re-sorted down into lower ventile groups. Those remaining in the now more-exclusive higher ventiles may show higher average longevity. Moreover, as men are re-sorted out of the high earnings ventiles downward, they could pull up the longevity in each successive lower ventile compared to the baseline sort.

The results are graphed for the 1938–1940 cohorts of men in figure 9. The longevity gradient between the first and last ventile is 8.3 years using the Canadian earnings thresholds and 9.6 using the US thresholds, a difference

20 The OLS regression of life expectancy on a country dummy, a linear slope term and their interaction delivers a Canadian slope estimate of 0.238 (0.020) and an estimate for the slope differential of 0.229 (0.028).

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

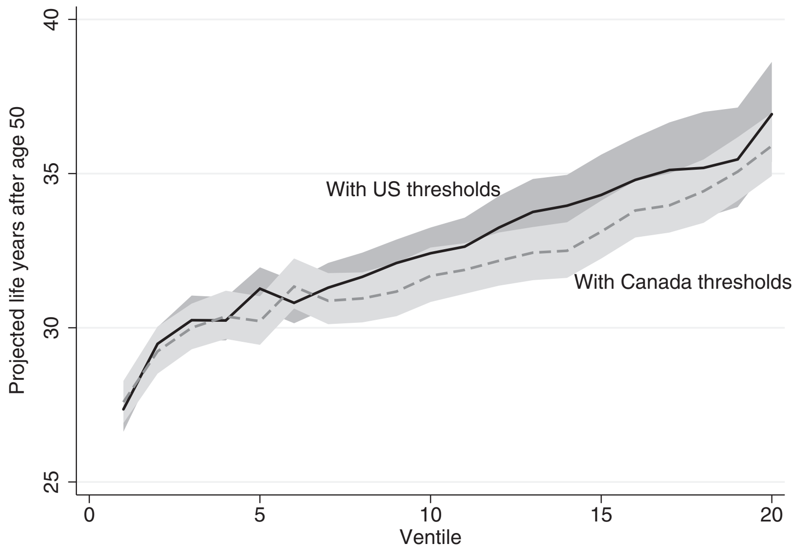

FIGURE 9 Canadian male life expectancy using Canada and US earnings ventile thresholds

NOTES: Data for Canada are from the OCA administrative file of the Canada Pension Plan. Men born between 1938 and 1940 are used for this analysis. The data are sorted into earnings ventiles based on the Canadian and US earnings distributions as described in the text. Shaded areas indicate 95% confidence intervals.

of 1.3 years, which is much smaller than the Canada–US gap. While the confidence intervals at each ventile taken one at a time overlap, the average difference between the slopes is still statistically significant. Using a simple linear regression to obtain the slope differential, we find an estimate of 0.06.[22] In section 7.2, we found the Canada–US slope differential using comparable methods to be 0.23. So, Canada–US earnings differences take back about 25.1% of the difference in the longevity gradient.

This analysis suggests that the earnings differences between Canada and the US are important to consider but still leave a substantial differential in the earnings–longevity gradient unexplained.

7.4. Canadian Case–Deaton effect

We now consider the mortality rates of middle-aged men in light of the Case and Deaton (2015, 2017) findings from the United States. The heightened "deaths of despair" in the United States from drugs, alcohol and suicide may reflect economic or social factors that also manifest in Canada. On one hand, the Canadian economy since 2000 overall has followed a different path than the United States, with a natural resources boom that boosted the labour

22 The coefficient in the regression for the differential slope term is 0.057 (0.027).

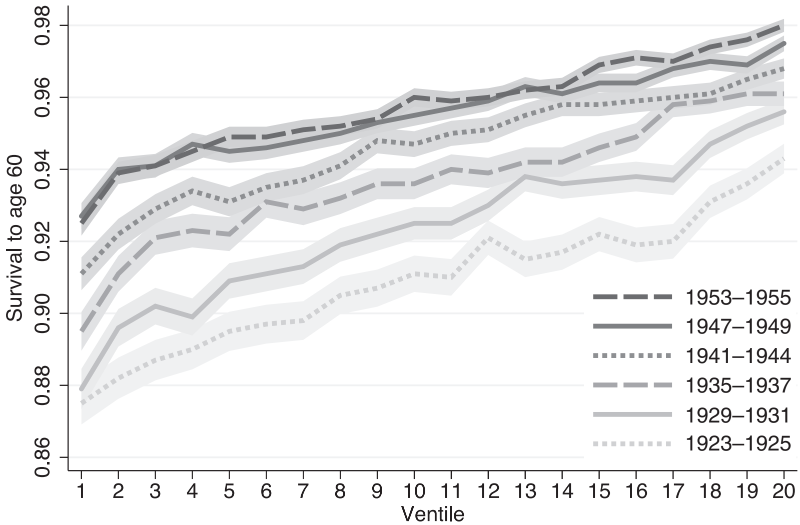

FIGURE 10 Age 60 survival for men by three-year cohort
NOTES: Data are from the OCA administrative file of the Canada Pension Plan. We show the survival at age 60 conditional on survival to age 50, with calculated 95% confidence intervals shaded.

market in some regions.[23] On the other hand, regions with a traditional manufacturing base have been affected in ways similar to manufacturing 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 Canadian survival rates between the ages of 50 and 60 for men. 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 coarse.

We graph survival rates in figure 10 using birth cohorts of men in three-year groupings from 1923–1925 to 1953–1955. We show only every second group of three years in order to keep the presentation of results clear. The calculated 95% 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) tighter and also because we are able to use observed survival rates without reliance on more-variable projections of life expectancy.

The survival rates of each cohort 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 different. The survival rates are right

23 Milligan and Schirle (2019) provide a comparison of the Canadian and American labour market outcomes in the 1990s and 2000s.

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 survival of men, but we do observe a sudden cessation of survival improvements.

8. Discussion

Our results reveal a steep longevity gradient in Canada but also sharp differences in this gradient and the evolution of longevity in Canada and the United States. The earnings–longevity gradient appears steeper in the United States, with the difference largely concentrated in the bottom half of the earnings distribution. While longevity gains over time 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 our findings. Of course, causally isolating factors that explain this broad cross-cohort change is difficult, and we do not 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.

The first possibility we consider is health insurance differences between Canada and the United States. While this seems an obvious place to start the comparison, several factors weigh against this explanation. First, a model presented by Lleras-Muney and Moreau (2019) frames mortality as a function of an initial endowment of frailty (as in Vaupel et al. 1979) and investments, shocks and depreciation that shift the initial endowment of frailty period by period as one ages. As mortality then depends on the history of shocks and investments over one's lifetime, we may not expect 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, evidence from the US on the impact of health insurance on mortality has been mixed.[24] 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.[25] If differentials in young-age access to universal public health insurance were important, we might expect to see different longevity gradients across the birth cohorts of

24 Recent work by Miller et al. (2019) studies Medicaid expansions, finding a significant drop in mortality among newly eligible Americans. That paper provides a comprehensive review of the recent literature. Earlier evidence from the introduction of Medicare in the United States in Finkelstein and McKnight (2008) found no estimated effect on mortality, although there was a substantial impact on out-of-pocket health expenses. See Cutler et al. (2006) for an earlier review of the literature.

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

Canadians, which we do not. Finally, universal public health insurance is present in both Denmark and Norway, but Kreiner et al. (2018) and Kinge et al. (2019) both find increasing longevity inequality for those countries. These four arguments tend to downgrade the importance of health insurance as a complete 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 behaviours.[26] Cutler et al. (2006, p. 115) argue 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. Recent evidence suggests that differences in health behaviours may have substantial long-run impact on survival after age 50 (Li et al. 2018). However, for the information and health behaviour explanation to hold, Canada–US differences in education and cognition across the whole bottom half of the earnings distribution would need to be evolving in sharply different directions.

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.[27] In the Lleras-Muney and Moreau (2019) model, the continuing drag of bio-psychological reactions to stress 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.[28] However, it is not clear this gap favoured Canada in the middle part of the 20th century, when several of the cohorts we study had already entered adulthood. In addition, the cases of Denmark and Norway cited above where strong social safety nets are in place do not reinforce the case for social safety nets being sufficient as an explanation. Looking at lifetime wages, Canadian lifetime wages were lower for the birth cohorts we consider, so it is not clearly the case that lifetime economic resources or social support were sufficiently different over the bottom half of the earnings distribution to explain the Canada–US difference in longevity trends.

While none of these explanations is completely satisfying in itself, they all may contribute in part. Further research to disentangle the causal contributions would provide much insight.

26 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.

27 Bio-psychological reactions to such circumstances can build up an allostatic load through constant exposure to stress hormones like cortisol. The concept of allostasis originates in McEwen and Stellar (1993) and describes the accumulating wear and tear on the body of chronic stress.

28 See Hoynes and Stabile (2019) for the case of families with children.

9. 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% difference in lifespan. In sharp contrast to the United States, the evolution of this earnings–longevity gradient over time has followed a mostly uniform shift, with equal improvements among high and low earners. We provide evidence against earnings growth as an explanation for the longevity improvements, suggesting other social and economic factors matter more. We perform a comparison of cohort-based and period methods, finding in our case that the cohort-based analysis shows steeper earnings–longevity gradients. We then calculate estimates for Canada and the US using comparable methodology and find the slope of the earnings–longevity gradient in Canada is about half that in the US. About one quarter of this difference is accounted for by Canada–US earnings differences. Finally, echoing Case and Deaton (2015, 2017), we find that improvements in survival for middle age men in Canada have stopped upward progress for those born in the 1950s, although we find no reversal in mortality rates for this subsample as has been found in the US. The paper closes with a discussion of several possible explanations for the Canada–US difference, ranging from health insurance to education and health behaviours to stress and hardship.

We conclude by noting that neither theory nor existing evidence provides a clear indication which of these explanations may hold. As the relationship between longevity and socio-economic status is fundamental to the distribution of older-life well-being and the design of social programs, understanding the sources driving the evolution of longevity should be a priority for future research.

Supporting information

Supplementary material accompanies the online version of this article.

References

Ahmadi, S.S., and R. Brown (2018) "Key factors for explaining differences in Canadian pensioner baseline mortality," technical report 218049, Canadian Institute of Actuaries

Attanasio, O.P., and H. W. Hoynes (2000) "Differential mortality and wealth accumulation," *Journal of Human Resources* 35(1), 1–29

Auerbach, A.J., K. K. Charles, C. C. Coile, W. Gale, D. Goldman, R. Lee, C. M. Lucas, P. R. Orszag, L. M. Sheiner, B. Tysinger, D. N. Weil, J. Wolfers, and R. Wong (2017) "How the growing gap in life expectancy may affect retirement benefits and reforms," *Geneva Papers on Risk and Insurance–Issues and Practice* 42(3), 475–99

Baker, M., J. Currie, and H. Schwandt (2019) "Mortality inequality in Canada and the United States: Divergent or convergent trends?," *Journal of Labor Economics* 37(S2), S325–S353
Boisclair, D., J.-Y. Duclos, S. Marchand, and P.-C. Michaud (2015) "Une analyse économique de propositions visant à bonifier le couverture du risque de longévité," *L'Actualité économique* 91(4), 499–530
Bosworth, B., G. Burtless, and K. Zhang (2016) *Later Retirement, Inequality in Old Age, and the Growing Gap in Longevity Between the Rich and Poor*. Washington: The Brookings Institution
Canadian Human Mortality Database (2016) "Canadian Human Mortality Database," Department of Demography, Université de Montréal. Available at www.demo.umontreal.ca/chmd/
Case, A., and A. Deaton (2015) "Rising morbidity and mortality in midlife among white non-Hispanic Americans in the 21st century," *Proceedings of the National Academy of Science* 112(49), 15078–83
——— (2017) "Mortality and morbidity in the 21st century," *Brookings Papers on Economic Activity*, Spring, 397–476
Chetty, R., M. Stepner, S. Abraham, S. Lin, B. Scuderi, N. Turner, A. Bergeron, and D. Cutler (2016) "The association between income and life expectancy in the United States, 2001–2014," *Journal of the American Medical Association* 315(16), 1750–66
Cristia, J.P. (2007) "The empirical relationship between lifetime earnings and mortality," technical report 2007–11, Congressional Budget Office
Currie, J., and H. Schwandt (2016) "Mortality inequality: The good news from a county-level approach," *Journal of Economic Perspectives* 30(2), 29–52
Cutler, D., A. Deaton, and A. Lleras-Muney (2006) "The determinants of mortality," *Journal of Economic Perspectives* 20(3), 97–120
Cutler, D.M. (2019) "Life and death in Norway and the United States," *Journal of the American Medical Association* 321(19), 1877–79
Cutler, D.M., F. Lange, E. Meara, S. Richards-Shubik, and C. J. Ruhm (2011) "Rising educational gradients in mortality: The role of behavioral risk factors," *Journal of Health Economics* 30(6), 1174–87
Duggan, J.E., R. Gillingham, and J. S. Greenlees (2008) "Mortality and lifetime income: Evidence from U.S. social security records," *IMF Staff Papers* 55(4), 566–94
Duleep, H.O. (1989) "Measuring socioeconomic mortality differentials over time," *Demography* 26(2), 345–51
Feir, D., and R. Akee (2019) "First Peoples lost: Determining the state of status First Nations mortality in Canada using administrative data," *Canadian Journal of Economics* 52(2), 490–525
Finkelstein, A., and R. McKnight (2008) "What did Medicare do? The initial impact of medicare on mortality and out of pocket medical spending," *Journal of Public Economics* 92(7), 1644–68
Fischer, B., J. Rehm, and M. Tyndall (2016) "Effective Canadian policy to reduce harms from prescription opioids: Learning from past failures," *CMAJ* (188), 1240–44
Gavrilov, L.A., and N. S. Gavrilova (2011) "Mortality measurement at advanced ages: A study of the Social Security Administration Death Master File," *North American Actuarial Journal* 15(3), 432–47

Gavrilova, N.S., and L. A. Gavrilov (2014) "Mortality trajectories at extreme old ages: A comparative study of different data sources on US old-age mortality." Presented at Living to 100 Symposium, Society of Actuaries

Gompertz, B. (1825) "On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies," *Philosophical Transactions of the Royal Society of London* 115, 513–83

Hanratty, M.J. (1996) "Canadian national health insurance and infant health," *American Economic Review* 86(1), 276–84

Hoynes, H., and M. Stabile (2019) "How do the US and Canadian social safety nets compare for women and children?," *Journal of Labor Economics* 37(S2), S253–S288

Kinge, J.M., J. H. Modalsli, S. Øverland, H. K. Gjessing, M. C. Tollånes, A. K. Knudsen, V. Skirbekk, B. H. Strand, S. E. Håberg, and S. E. Vollset (2019) "Association of household income with life expectancy and cause-specific mortality in Norway, 2005–2015," *Journal of the American Medical Association* 321(19), 1916–25

Kitagawa, E.M., and P. M. Hauser (1973) *Differential Mortality in the United States: A Study in Socioeconomic Epidemiology.* Cambridge, MA: Harvard University Press

Kreiner, C.T., T. H. Nielsen, and B. L. Serena (2018) "Role of income mobility for the measurement of inequality in life expectancy," *Proceedings of the National Academy of Sciences* 115(46), 11754–59

Li, Y., A. Pan, D. D. Wang, X. Liu, K. Dhana, O. H. Franco, S. Kaptoge, E. Di Angelantonio, M. Stampfer, W. C. Willett, and F. B. Hu (2018) "Impact of healthy lifestyle factors on life expectancies in the US population," *Circulation* 138, 345–55

Lleras-Muney, A., and F. Moreau (2019) "A unified law of mortality: Implications for economic analyses," UCL technical report

McEwen, B.S., and E. Stellar (1993) "Stress and the individual: Mechanisms leading to disease," *Archives of Internal Medicine* 153(18), 2093–101

Meara, E., S. Richards, and D. Cutler (2008) "The gap gets bigger: Changes in mortality and life expectancy, by education, 1981–2000," *Health Affairs* 27(2), 350–60

Miller, S., S. Altekruse, N. Johnson, and L. R. Wherry (2019) "Medicaid and mortality: New evidence from linked survey and administrative data," NBER working paper no. 26081

Milligan, K., and T. Schirle (2019) "Push and pull: Disability insurance, regional labor markets, and benefit generosity in Canada and the United States," *Journal of Labor Economics* 37(S2), S289–S323

Mustard, C.A., A. Bielecky, J. Etches, R. Wilkins, M. Tjepkema, B. C. Amick, P. M. Smith, and K. J. Aronson (2013) "Mortality following unemployment in Canada, 1991–2001," *BMC Public Health* 13(441). https://doi.org/10.1186/1471-2458-13-441

Mustard, C.A., S. Derksen, J.-M. Berthelot, M. Wolfson, and L. L. Roos (1997) "Age-specific education and income gradients in morbidity and mortality in a Canadian province," *Social Science and Medicine* 45(3), 383–97

National Academies of Sciences, Engineering, and Medicine (2015) *The Growing Gap in Life Expectancy by Income: Implications for Federal Programs and Policy Responses.* Washington: National Academies Press

Office of the Chief Actuary (2015) “Canada Pension Plan Retirement, Survivor and Disability Beneficiaries Mortality Study,” Actuarial Study 16, Office of the Superintendent of Financial Institutions

Olshansky, S.J., T. Antonucci, L. Berkman, R. H. Binstock, A. Boersch-Supan, J. T. Cacioppo, B. A. Carnes, L. L. Carstensen, L. P. Fried, D. P. Goldman, J. Jackson, M. Kohli, J. Rather, Y. Zheng, and J. Rowe (2012) “Differences in life expectancy due to race and educational differences are widening, and many may not catch up,” *Health Affairs* 31(8), 1803–13

Orpana, H.M., J.-M. Berthelot, M. S. Kaplan, D. H. Feeny, B. McFarland, and N. A. Ross (2010) “BMI and mortality: Results from a national longitudinal study of Canadian adults,” *Obesity* 18(1), 214–18

Pappas, G., S. Queen, W. Hadden, and G. Fisher (1993) “The increasing disparity in mortality between socio-economic groups in the United States, 1960 and 1986,” *New England Journal of Medicine* 329(2), 103–109

Ross, N.A., M. C. Wolfson, J. R. Dunn, J.-M. Berthelot, G. A. Kaplan, and J. W. Lynch (2000) “Relation between income inequality and mortality in Canada and in the United States: Cross sectional assessment using census data and vital statistics,” *British Medical Journal* 320(7239), 898–902

Tjepkema, M., R. Wilkins, and A. Long (2013) “Socio-economic inequalities in cause-specific mortality: A 16-year follow-up study,” *Canadian Journal of Public Health* 104(7), 472–78

Vaupel, J.W., K. G. Manton, and E. Stallard (1979) “The impact of heterogeneity in individual frailty on the dynamics of mortality,” *Demography* 16(3), 439–54

Waldron, H. (2007) “Trends in mortality differentials and life expectancy for male social security-covered workers, by socioeconomic status,” *Social Security Bulletin* 67(3), 1–28

——— (2013) “Mortality differences by lifetime earnings decile: Implications for evaluation of proposed Social Security law changes,” *Social Security Bulletin* 73(1), 1–37

Wolfson, M., G. Rowe, J. F. Gentleman, and M. Tomiak (1993) “Career earnings and death: A longitudinal analysis of older Canadian men,” *Journal of Gerentology* 48(4), S167–S179