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The unequal impact of the COVID-19 pandemic on life expectancy across Chile

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Title: The unequal impact of the COVID-19 pandemic on life expectancy across Chile

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Word count (main text, references): 2921

Abstract (205 words):

Objectives: To quantify the effect of the COVID-19 pandemic on life expectancy in Chile categorized by rural and urban, and to correlate life expectancy changes with socioeconomic factors at the municipal level.

Design: Retrospective cross-sectional demographic analysis using aggregated data.

Setting: Vital and demographic statistics from the national institute of statistics and department of vital statistics of ministry of health.

Participants: Aggregated national all-cause death data stratified by year (2000-2020), sex, and municipality.

Main Outcome measures: Stratified mortality rates using a Bayesian methodology. With this, we assessed the unequal impact of the pandemic in 2020 on life expectancy across Chilean municipalities for men and women and analyzed previous mortality trends since 2010.

Results: Life expectancy declined for both men and women in 2020. Urban areas were the most affected, with males losing 1.89 and females 1.33 in 2020. The strength of the decline in life expectancy correlated with indicators of social deprivation and poverty. Also, inequality in life expectancy between municipalities increased, largely due to excess mortality among the working-age population in socially disadvantaged municipalities.

Conclusions: Not only do people in poorer areas live shorter lives, they also have been substantially more affected by the COVID-19 pandemic, leading to increased population health inequalities. Quantifying the impact of the COVID-19 pandemic

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on life expectancy provides a more comprehensive picture of the toll.

Keywords: COVID-19, Latin America, Mortality, Life expectancy, Health Inequalities

Strengths and limitations

- First study to analyze changes in life expectancy in Chile with small-area resolution.
- We applied a hierarchical Bayesian methodology to estimate life expectancies in the past 20 years.
- We show that COVID-19 led to declines in life expectancy in Chile greater than a year in magnitude. These declines correlated with poverty levels, indicating that socially deprived populations were hit the hardest.
- We also show that inequality in life expectancy between municipalities increased due to excess mortality among the working-age population in socially disadvantaged municipalities.
- The main limitation is that our estimates depend on accurate small-area stratified population estimates. We implemented several estimates and showed that our findings are robust to the choice of them.

Main Text

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Introduction

Most Latin American countries experienced substantial progress in reducing premature mortality while increasing health standards over the last century and into the first fifteen years of the twenty-first century.[1,2] But this progress has been reversed, as Latin American countries have been severely affected by the COVID-19 pandemic.[3] The region became the hotspot of the pandemic in June 2020 and by May 2021 more than one million COVID-19 deaths have been reported.[4,5]

After decades of sustained improvements in life expectancy, leading to levels comparable to low mortality countries, Chile experienced losses in this indicator in 2020 due to increased excess mortality during the COVID-19 pandemic (11 months for women and 1.3 years among men).[6] While national figures are important and informative, they conceal heterogeneity at the subnational level, which can be substantial. Emerging evidence from Latin American countries suggests that the COVID-19 pandemic has disproportionately affected disadvantaged groups with low socioeconomic status as well as indigenous people, with large regional variation.[7-10] In Chile's capital, Santiago, areas with low socioeconomic status experienced poorer health interventions, and substantial excess mortality coupled with higher number of deaths and infection fatality rates at younger ages.[7] Similarly, municipalities with higher proportions of indigenous population showed higher mortality from COVID-19.[8] It is unclear, however, what the net effect of increased mortality has

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been on life expectancy at a more granular level of geography and by population subgroups in Chile.

In this context of persistent and pervasive health inequalities, varied mortality impacts by age and sex, and regional variation, it is imperative to analyze how has life expectancy been affected differently across Chile. Due to the heightened risk to COVID-19 and mortality of disadvantaged populations, most deprived areas may have experienced greater losses in life expectancy, especially among men. Similarly, since rural and urban areas may be affected differently, and mortality increased among young working-age men, we hypothesize that younger age excess mortality will have a substantial effect on life expectancy losses potentially increasing disparities at the municipality level. This hypothesis is supported by evidence from Chile's capital suggesting that urban and more crowded areas have experienced worse health outcomes during the pandemic.[7,11] Alternatively, since death rates increased exponentially with age and losses in life expectancy in low mortality countries have been attributed mostly to mortality above age 60,[6] another hypothesis is that the pandemic in 2020 was such a strong shock that excess mortality differentials decreased, leading to reducing inequalities between municipalities.

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This article contributes towards a more comprehensive understanding of the COVID-19 pandemic's burden on population health by estimating life expectancy across Chilean municipalities by sex using a powerful Bayesian methodology.[12] We contextualize our results with past trends of progress and disparities in life expectancy, and categorize our findings by urban vs non-urban areas. Our study is a step towards explaining the varied impacts of the pandemic by analyzing trends in life expectancy over age at a more granular level and by correlating life expectancy losses with indicators of poverty in Chile.

Study Data and Methods

Data

We used data on births and deaths by age, sex and municipality from publicly available vital statistics.[13] These data were complemented with official population counts by age (single years of age grom 0 to 89 and collapsed in 90+), sex and municipality from the 2002 and 2017 censuses available from the National Institute of Statistics (INE).[14] We also used official population projections between 2002 and 2020 centered at the 2017 census.[15] Unlike censuses themselves, these projections collapsed all ages greater than 80 in one single group. We only observed minor changes in our estimates based on whether the open ended interval started at 80 or 90, but we did observe that life expectancy estimates based on 2017 projections were substantially higher than the ones based on the 2017 census. We explain this by a possible inadequacy of the official projection for later years. Because of this reason, we considered two alternative population estimates for 2017 onwards. The first one assumes that population counts remain fixed for years 2018,2019 and 2020. In the second one, we projected forward the population using the cohort

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component method[16] with 2017 as baseline assuming zero migration. We also used census data to classify municipalities as urban or non-urban. (See Supplementary Tables 1-3).[17] Data on poverty and crowdedness were taken from the CASEN survey by the Chilean Ministry of Social Development and Family.[18]

Mortality estimation

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Age specific death rates for each municipality by sex were estimated implementing a recently developed methodology[12] based on a hierarchical Bayesian model[19] using population and death counts.[17] There are two main advantages to this Bayesian methodology: first, by sharing information across global variables, it is possible to smooth out the noisy estimates that would otherwise be obtained if we relied only on empirical counts. This is important because of the increased likelihood of low death counts on each strata in small municipalities. Second, by appealing to the Bayesian methodology we obtain credible intervals for each of our estimates.

Life tables

Life tables were calculated using the age specific death rates estimated in the Bayesian procedure following standard techniques.[16] From these, period life expectancy at birth, temporary life expectancy between ages 20 and 65, and remaining life expectancy at age 65 were subtracted. Life expectancy at birth refers to the average years a cohort of newborns is expected to live given the current mortality conditions. Similarly, life expectancy at age 65 refers to the average years individuals aged 65 are expected to live if they were to experience the current mortality conditions throughout their lives. Given the emerging evidence about how younger age groups below age 65 have also been affected by the pandemic in the context of Chile, we constructed a measure to capture average longevity over working ages through temporary life expectancy. Temporary life expectancy between ages 20 and 65 refers to the average years lived between these ages given prevalent mortality conditions.[20] For example, if no one were to die between these ages, then the temporary life expectancy would be the full 45 years. To complement our analysis we also consider the probability of not reaching age 65 as an indicator of premature mortality. As a measure of inequality between municipalities we calculated the Gini coefficient of life expectancy across municipalities.[21] The Gini coefficient is a standard indicator of inequality employed in social sciences. In the context of this paper, the Gini coefficient expresses the degree of inequality in life expectancy across municipalities.

Limitations

This study had several limitations. First, while Chile's vital registration is one of the most reliable in Latin America, there are likely to be inaccuracies in mortality registration due to age misreporting and coverage across municipalities, as well as systematic age overstatement.[22] Delays in recording deaths may lead to incompleteness issues especially in urban areas. Our results on life expectancy declines and mortality inequalities may be

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considered a lower bound because of these issues. The effect of systematic age overstatement is likely to affect our results too. However, there is no information on what the age pattern of overstatement is during the pandemic. To mitigate these inaccuracies and their effects on our life expectancy estimates, we used a hierarchical Bayesian model that helped to retrieve a reasonable mortality profile across regions. Another limitation is that because of the low number of deaths observed in some municipalities, the degree of uncertainty around the estimates was very high, not allowing us to include them in our analysis with confidence. We excluded municipalities by sex with less than 16,000 people (as per the 2017 census), as we observed that life expectancy estimates were unstable even with our adopted Bayesian methodology. However, we grouped them together and reproduced all results to avoid systematic exclusion. Results were consistent and are shown in Supplementary Figure 2.[17] Almost all of these were all non-urban municipalities. Some other municipalities were excluded based on a visual inspection of mortality trends that were clearly indicative of coding errors in the mortality database (see Supplementary Figure 1) Despite these limitations, we used the most reliable data for Chile and state-of-the-art methodologies to gauge mortality dynamics across Chile. Finally, our results are limited in that stratified population counts are typically model-based estimates (except at census years), and might be biased. We studied the effect of alternative population estimates in final outcome measures, as described in the Supplement (Figures 3-17).

Study Results

Trends in life expectancy at birth and survivorship below age 65.

Men and women from both urban and non-urban areas experienced steady increases in life expectancy at birth from 2010 to 2019. Women showed higher life expectancy at birth than men in all groups. In contrast, higher mortality during 2020 led to sharp decreases in life expectancy at birth (Figure 1). Life expectancy among men in urban and non-urban areas declined by 1.89 (1.68,2.09) and 1.66 (1.5,1.8) years, respectively. Among women, life expectancy losses were 1.33 (1.11,1.55) and 1.10 (0.918,1.28), respectively. The magnitude of the decline from 2019 to 2020 offset most gains in life expectancy experienced in the last decade, especially in urban areas. In fact, 68% of the municipalities analyzed ended up with lower life expectancy than in 2015, and this number rose to 75% in urban municipalities.

Decreases in the probability of surviving to age 65 (Figure 2) indicate that these declines cannot be fully attributed to increased mortality in older age groups only. While mortality above age 65 has been documented as one of the main contributors to declines in life expectancy internationally, substantial increases in mortality below age 65 are apparent in our results, especially among men in urban areas.

Changes in disparities in life expectancy during the COVID-19 pandemic in 2020

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Figure 3 shows the year-to-year relative changes of the Gini coefficient as a measure of inequality in life expectancy across municipalities. Panel A refers to life expectancy at birth, panel B to life expectancy between age 20 and 65, and panel C to life expectancy at age 65. From our results it emerges that inequality increased substantially in urban areas from 2019 to 2020 in comparison with previous years, with changes oscillating around 25%. The magnitude of increase is much larger in men and women's life expectancy between ages 20 and 65 from urban areas (50.9% and 50.6% for men and women respectively). Altogether, these results indicate not only that mortality during 2020 became more unequal, but that this inequality was driven mostly by the younger age group. Supplementary Figures 14-17 show that larger variation in 2020 compared with previous years was driven by lower values of life expectancy.

To better understand the factors driving this spike in inequality, we investigated how declines in life expectancy during 2020 correlated with social deprivation indicators including poverty and crowdedness focusing only on mortality above age 20 across urban areas. Figure 4 shows the relationship between poverty and life expectancy between age 20 ang 65 and life expectancy at age 65. To underscore how the relationship changed in the course of 2020, we stratified the results juxtaposing the previous five years (2015-19) with 2019-20. Results show a strong historical negative correlation between life expectancies in both age groups, sexes and poverty levels. Males in the top poverty decile have a 4.39 expectancy lower life expectancy than in the bottom decile. They also live on average

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0.92 less years between 20 and 65, and 2.22 from 65 onwards. For females, these numbers are 2.51, 0.31 and 1.55 years. During 2020, the slope became more negative, suggesting that those municipalities with higher levels of poverty experienced greater losses in life expectancy. This dependency was stronger in the younger age group.

In contrast, while life expectancy at 65 declined during 2020, this decline was less unequal over the poverty gradient, consistent with the hypothesis that this group contributed less to inequality in changes in life expectancy. To formalize these observations, we performed regression analyses to model the interactions between year and poverty level through varying intercepts and slopes. We only found significant changes in slope for average years lived between 20 and 65. For males, this translated into an additional difference of 0.78 years between the highest and lowest poverty deciles (p=0). For females, this difference was 0.3 (p<0.001)

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Discussion

Urban areas that are exposed to higher poverty or social disadvantages experienced larger losses in life expectancy during the COVID-19 crisis in 2020 in Chile. Our results reveal that losses were unevenly shared across municipales, over age, and by sex, leading to increasing inequality in life expectancy across regions in Chile. Moreover, consistent with previous research on increased mortality at younger ages in 2020 in deprived municipalities in Chile’s capital,[7] our research shows that working age mortality was one of the main drivers of increasing inequality in life expectancy across Chile.

Analysis of life expectancy in 2020 compared with the previous five years (2015-19) show that poorer urban municipalities suffered a double burden. Not only did they show lower levels of life expectancy but they also experienced greater losses in life expectancy. This is consistent with previous research documenting larger mortality increases for the lower educated groups in Chile's capital.[23] Furthermore, when we disaggregate by age groups, we observe that the association between life expectancy for working age individuals (between ages 20 and 65) and levels of poverty became stronger compared to previous years. This is a surprising finding given that previous evidence had documented a positive association between income and life expectancy at retirement.[24] This suggests that even if the burden of mortality during the COVID-19 crisis has been concentrated at older ages,[25] contributing substantially to life expectancy declines during 2020,[6] inequalities in life expectancy were largely driven by increased mortality in working ages at higher levels of poverty. A potential explanation is that the working age population's availability to work from home and be less exposed to heightened risk of COVID-19 and its consequences varies across municipalities. Deprived populations in Chile's capital experienced higher fatality rates as a consequence of worse baseline individual health status and to an overwhelmed healthcare system.[7] Similarly, evidence from the US suggests that those individuals with less availability to work from home had higher death rates compared to those that could afford working from home in 2020.[26]

An open question is whether this sudden increase in inequality amounts to a shock that will be followed by a recovery to pre-pandemic levels, or whether these changes will persist in the long term. Beyond the immediate increase in premature mortality, this is relevant because failing to acknowledge inequalities in mortality may compromise the progressiveness and actuarial fairness of social security and public pension systems in the long term,[27,28] which could be translated into higher mortality in the future. Similarly, the scars left by the pandemic, including a weak health system, may increase mortality from multiple causes of death. For example, postponed cancer treatments and failure to detect other chronic degenerative diseases timely may lead to lower levels of life expectancy in the long term than it was projected. This highlights the need for accurate and timely data on other causes of death. Future analysis should focus on analyzing the consequences of the COVID-19 pandemic, including multiple causes of death and diseases to study the direct effects from COVID-19 mortality as well as the indirect effects through other pathways of diseases and conditions.[29] Our research, in this sense, provides a first outlook by focusing on all-cause mortality.

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As shown by our results, the case of Chile underscores the dire widening of an already large mortality gap between those living in deprived conditions and those living with higher income during the COVID-19 crisis. Evidence shows that the health consequences of external shocks such a pandemic or an economic crisis are not spread equally across social deprivation levels.[30] The COVID-19 pandemic reminds us of the ever-present risk of such events, whose cumulative effect may partially explain the ever-existing gaps in mortality. Therefore, the way that this crisis has exposed the vulnerabilities of socially deprived populations is a call to challenge the monolithic view of a country's demographics in the design of social security systems. New strategies incorporating a public health perspective that considers widening inequalities should be implemented to minimize the effects of the COVID-19 pandemic on the health status of the Chilean population both immediately and in the long term.

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Author contributions: GM, data curation, software, validation GM and JMA formal analysis, investigation,conceptualisation, methodology, project administration, resources, validation, visualisation,

writing (original draft), and writing (review & editing) JMA funding acquisition, supervision

Ethics approval: This research project does not require ethics approval as it uses only macro data that are freely available online.

Conflict of interest: None declared.

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Figure legends:

Figure 1

Life expectancy at birth by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 2

Probabiltiy of not surviving to 65 years by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 3

Relative yearly changes in Gini with respect to previous years (starting 2002) for life expectancy at birth (A), average years lived between 20 and 65 (B) and life expectancy at 65.

Figure 4

Changes in inequality of mortality in 2020 with respect to recent history were stronger in younger age groups. A Comparison between 2015-2019 and 2020 of the average years lived between 20 and 65, for males and females, as a function of poverty. B same as in A, but with life expectancy at 65.

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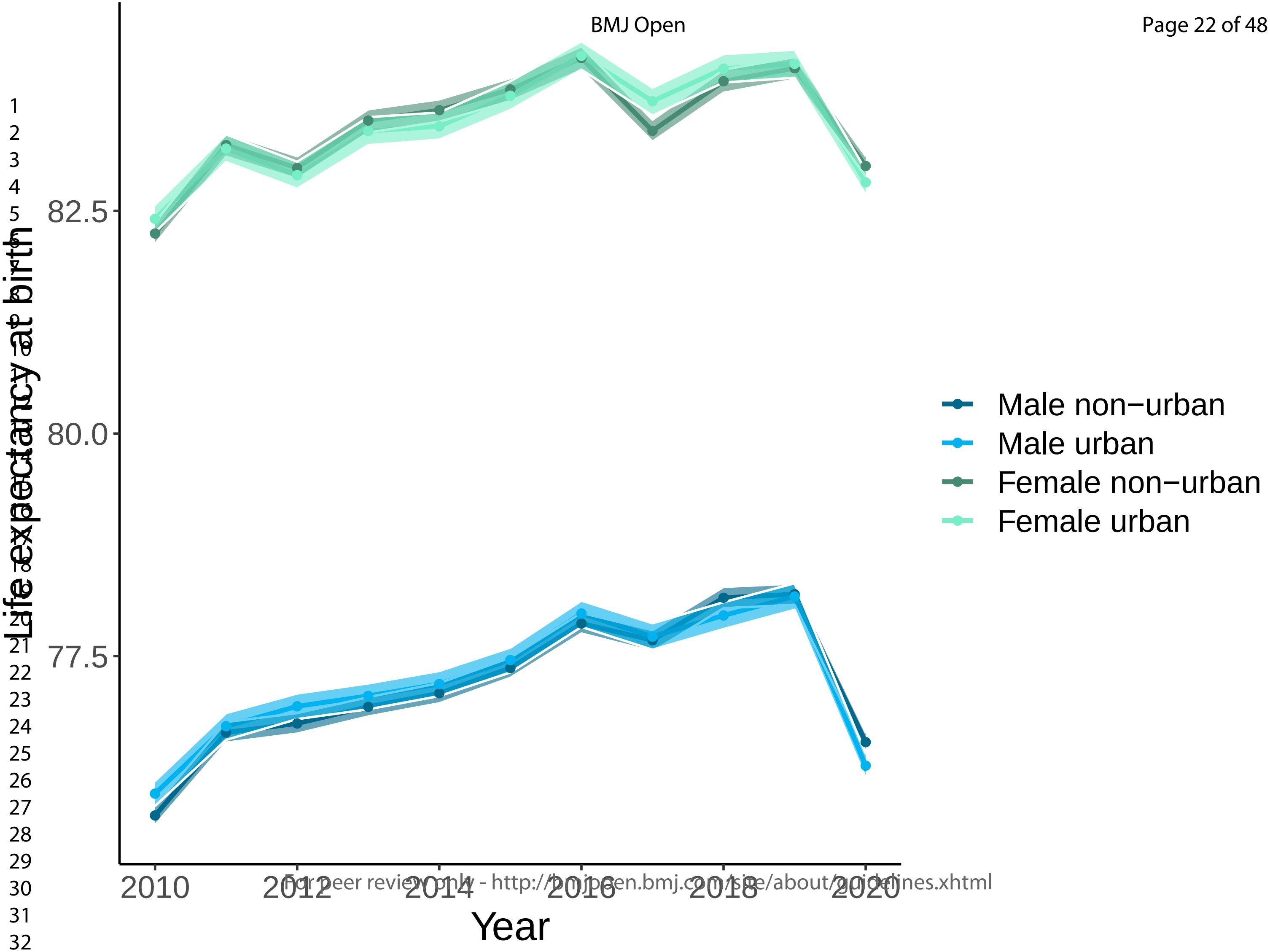
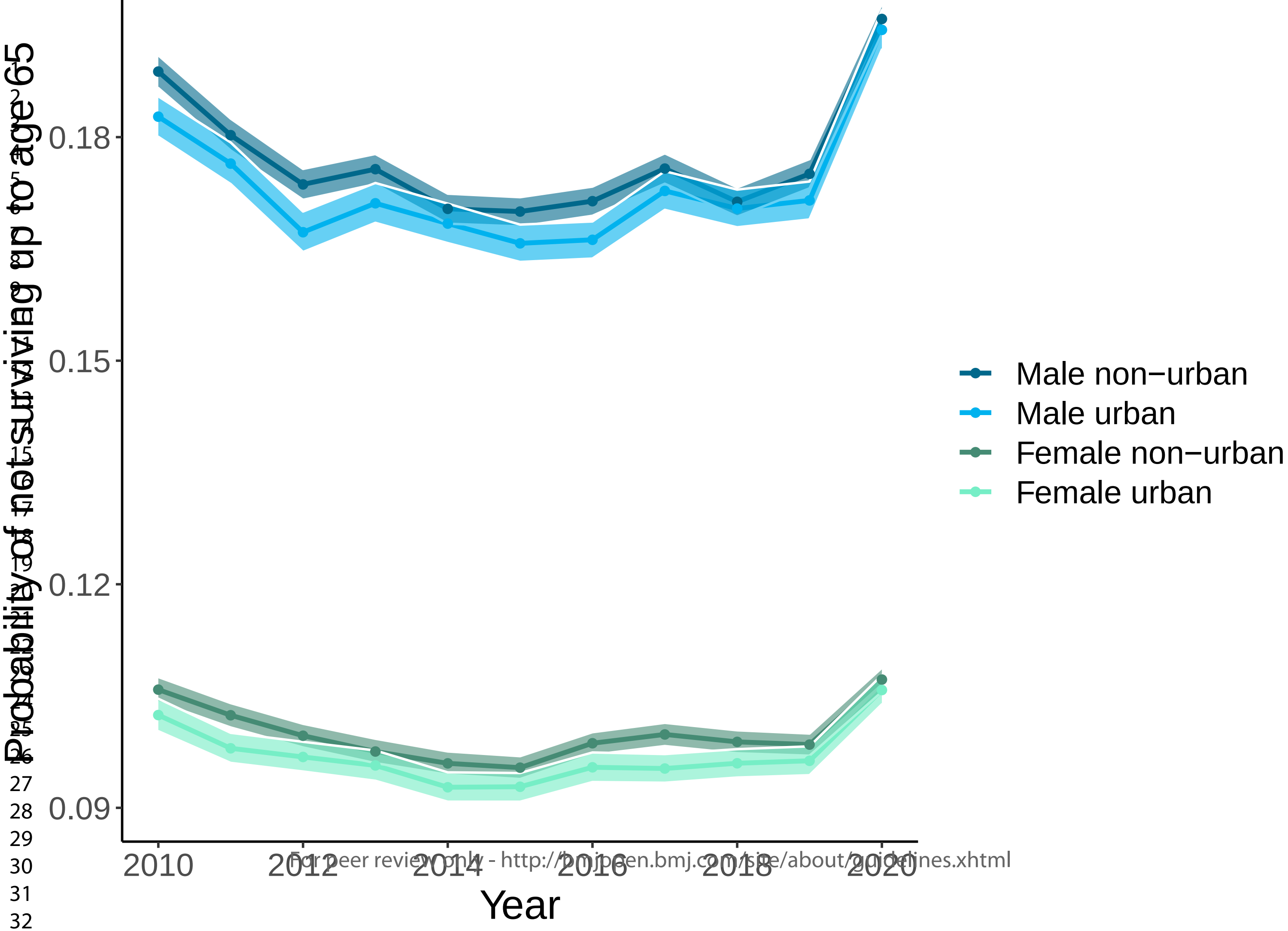
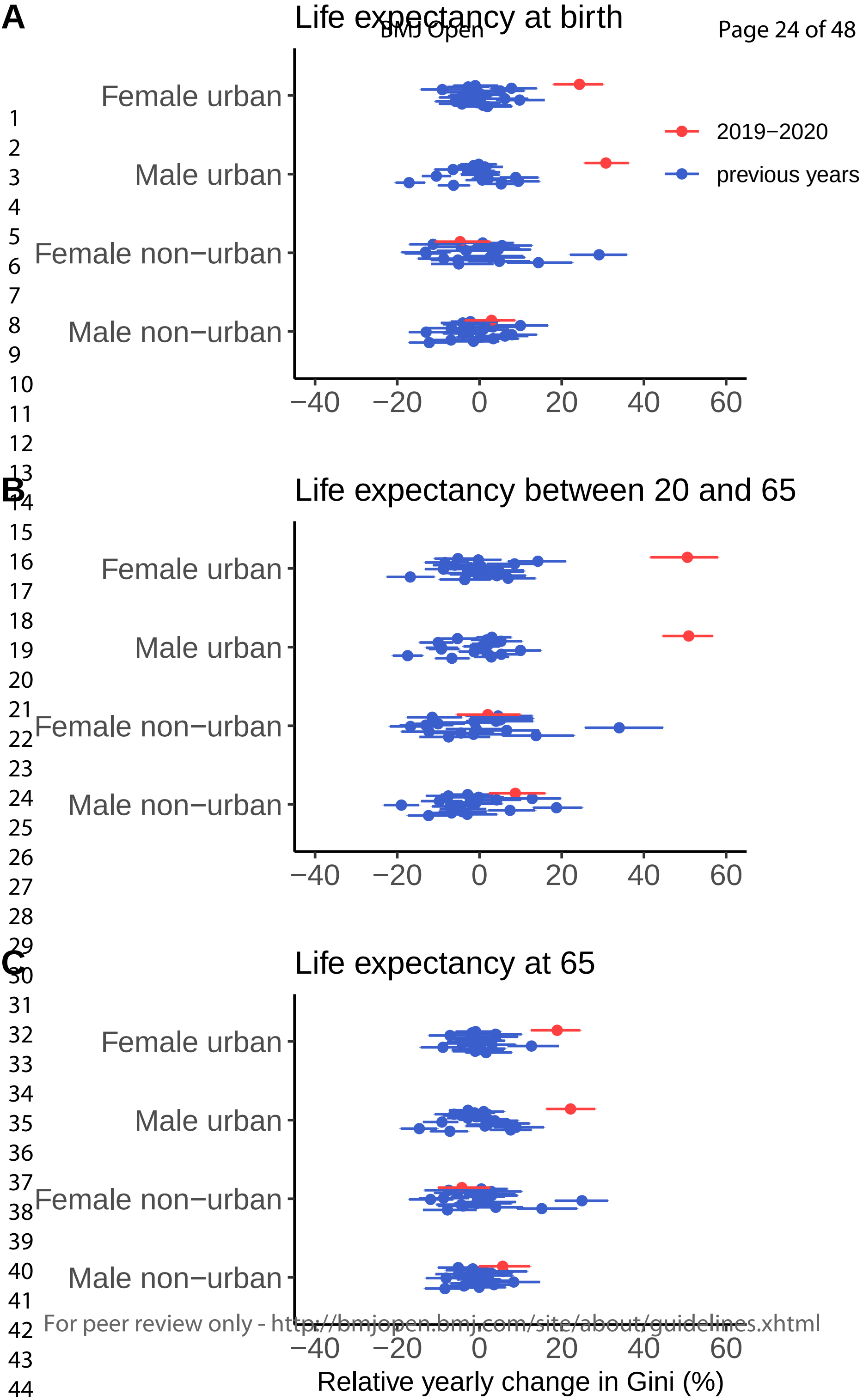
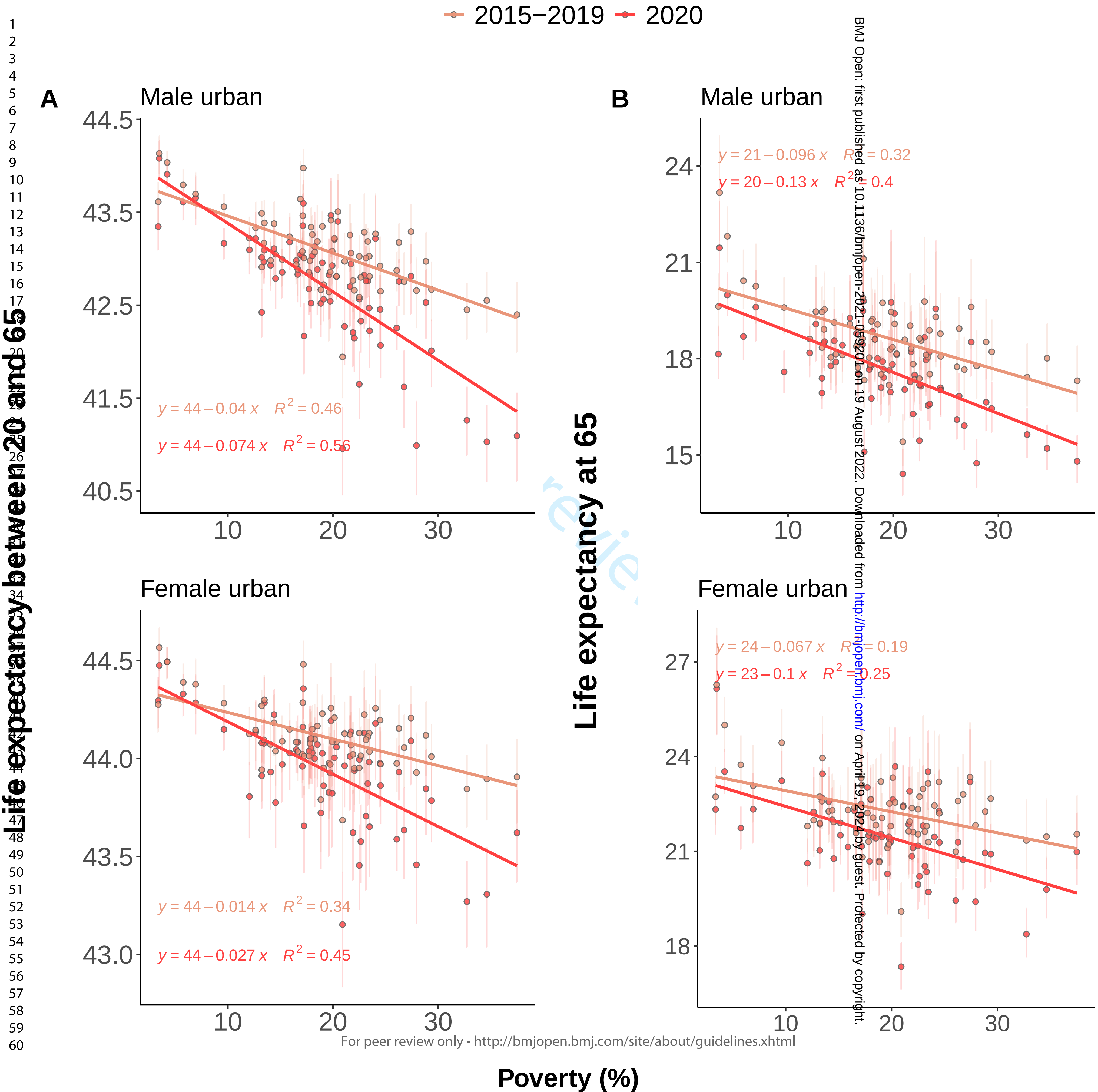

Life expectancy at birth
82.5
80.0
77.5
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban


Probability of not surviving up to age 65
0.18
0.15
0.12
0.09
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban


A
Life expectancy at birth
Female urban
Male urban
Female non−urban
Male non−urban
−40
−20
0
20
40
60
2019−2020
previous years
B
Life expectancy between 20 and 65
Female urban
Male urban
Female non−urban
Male non−urban
−40
−20
0
20
40
60
C
Life expectancy at 65
Female urban
Male urban
Female non−urban
Male non−urban
−40
−20
0
20
40
60
Relative yearly change in Gini (%)



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The unequal impact of the COVID-19 pandemic on life expectancy across Chile: Supplementary materials

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1 Municipality classification

Chile is composed by a total of 16 regions. Each region is divided into smaller units, called municipalities. There are a total of 366 municipalities. We classified them as urban or non-urban based on the same criterion as in (*1*), that is, if the following two conditions hold: i) population density greater than 70 people per square kilometer, and ii) the proportion of people living in a urban environment is greater than 88%. We excluded all municipalities having fewer than 16,000 people according to census. In Tables 1 and 2 we show the total number of people and municipalities on urban, non-urban and excluded municipalities. The names of all municipalities and their urbanity status is shown in Table 3. We note that although 147 out of 339 municipalities where excluded, this only signifies a 7% of the population.

To study whether excluding small municipalities would bias our results, we created a super-municipality made by all the excluded. Notably, only two (out of 147) municipalities in this group would have been otherwise categorized as urban (El Quisco, Algarrobo), so it is safe to assume that this super-municipality is a non-urban one. In Fig. 2 we compare time evolution of life expectancy at birth and probability of dying before reaching age 65 (Exhibit 1 and 2 of the main text) for the non-urban municipalities, along with the values for the excluded (mostly non-urban) super-municipality. These are in close agreement.

2 Estimation of mortality rates

We implemented method of (*2*), which consists on a hierarchical Bayesian model for the estimation of age-specific mortality rates on small area setups. The main idea is that by modeling a joint structure for these rates as a function of time and space, it would be possible to smooth out the effect of poor empirical estimates for years/locations where only a few population counts were available. In practice, we found that estimates were reasonable as long as the population of municipalities was reasonably large. We applied the algorithm to all municipalities for each region, and each year between 2002 and 2020, separating by gender (male, female, all). This gave a total of 16×3 algorithm runs. For each a run, we obtained a total of 3,000 Monte Carlo samples that we used for computing credible intervals. Additionally, we ran the algorithm to compute mortality rates for each region, and for the totality of urban and non-urban municipalities, as necessary. In all cases, we estimated mortality rates based on 5 years intervals, up to age 80+ (see below for a discussion of the cutoff age).

We excluded from our analyses some municipalities/years based on the visual inspection of total deaths per year. A cluster of 6 municipalities appeared to have corrupted data in the years surrounding 2004. Those are shown in Fig. 1.

3 Regressions

4 Sensitivity analyses

Since deaths are revealed to us in full detail, and because Chilean death recording system is reliable (*3*), the main source of corruption in mortality rates should stem from possible biases in population estimates. We explored what was the impact of different ways using population estimates in constructing the life tables, and used a number of several alternative estimates to re-create the results shown in the main text. These are explained below.

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Improving official projections

For year specific population counts between 2002 and 2020, we used the official population projections provided by the national institute of statistics, available at the municipality level and with resolution of years. These are made with simple interpolation and extrapolation methods as described in (*4*). However, we found that these projections were often inconsistent, mostly from 2017 on. Therefore, we considered two alternative estimates in addition to official projections, that only differed from official estimates starting 2017. For one estimate we used the official census counts at 2017 for years 2018, 2019 and 2020. The second estimate corresponds to the cohort survival (or component) projection method, where we used births in 2017 (the only available) and deaths in 2018, 2019, 2020 to infer municipality and age specific population counts after 2017. In Fig. 5 we show comparisons between resulting estimates. We observe that indeed they produce different estimates, and differences between methods increase for later years. Notably, estimates based on official projections deviate wildly from other in some municipalities, indicating a possible lack of accuracy. In particular, we should expect that estimations based on projections at census year 2017 should be similar to the ones provided by our alternative estimates.

Maximum age

Another source of bias is given by cutoff age used when turning age-specific mortality rates into life expectancy estimates. Official census information (2002,2017) contains age-specific population counts for each municipality and gender, up to age 90. However, official census projections collapses all ages above 80 into one group. In Fig. 5A we compare results with the 80 and 90 cutoff, using official census data (only years 2002 and 2017), We observe that the 90 cutoff leads to consistently slightly higher life expectancies, with a difference that appears higher for older ages. Importantly, in 5B,C we also include other estimates, for reference. We observe large discrepancies in year 2017 when comparing official census and official projections. Once

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more, this is an indication that official projections are not accurate, as they become inconsistent in 2017 (i.e., official projections in year 2017 are far from official census in the same year).

Main results with alternative estimates In the main text we have used the cohort survival projection method. Here, we present results using the other two alternative methods. Figs. 5 and 6 correspond to Exhibits 1 and 2 in the main text, respectively. Figs. 7 and 8 complement Exhibit 3, and likewise, Figs. 9 and 10 complement Exhibit 4.

5 Additional results

We provide additional figures that supplement exhibits in the main text. In Fig. 11 we show histograms of the life expectancy (with each sample representing a municipality) at even years. We observe that a left tail appears during 2020 (mostly in urban setups) indicative of the unequal impact of COVID-19 in some municipalities. Fig. 12 supplements Exhibit 3 in the main text, but showing the entire Gini time series, and not only the year-to-year differences. A clear abrupt increase is observed during 2020. Interestingly, a consistent temporal drop in Gini is observed between 2002-2019 (with the exception of 2010, when an earthquake caused hundreds of casualties localized in space), for life expectancies between 20-40. Finally, Fig.13 supplements Exhibit 4 by showing the relation between life expectancy and poverty in non-urban municipalities. No clear consistent pattern is observed. Also, in Fig. 14 we show the corresponding decreases of life expectancy over time as a function of poverty, in urban and non-urban setups. This figure is complemented by Fig. 15, which shows an even stronger correlation when using crowdedness as covariate, and Figs. 16 and 17, which show sensitivity of Fig. 14 to changes in the projection methodology.

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Region	Urban	Rural	Excluded	Total
Tarapaca	299843	0	30715	330558
Antofagasta	0	552790	54744	607534
Atacama	448784	251371	57431	757586
Coquimbo	880647	787549	139030	1807226
Valparaíso	0	223516	62652	286168
O'Higgins	275211	477699	161645	914555
Maule	369493	559301	116156	1044950
Biobio	946952	504405	105448	1556805
La Araucanía	282415	522213	140985	945613
Los Lagos	407362	262009	159337	828708
Aysen	0	81777	20233	102010
Magallanes	0	153069	12304	165373
Metropolitana	6273435	809613	29760	7112808
Los Ríos	166080	181799	36958	384837
Arica y Parinacota	0	221364	4704	226068
Nuble	215646	152749	100611	469006
Chile	10565868	5741224	1232713	17539805

Table 1: Number of municipalities for each strata (urban, rural) in our design, for each region.

References

1. J. Berdegué, E. Jara, F. Modrego, X. Sanclemente, A. Schejtman, *Rimisp, Santiago* (2009).

2. M. Alexander, E. Zagheni, M. Barbieri, *Demography* **54**, 2025 (2017).

3. G. E. Mena, *et al.*, *Science* **372** (2021).

4. I. N. de Estadísticas, Estimaciones y proyecciones de la población de chile 2002-2035 a nivel comunal. documento metodológico (2019 [Online].).

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		Urban	Rural	Excluded	Total
Region	Tarapaca	2	0	5	7
	Antofagasta	0	3	6	9
	Atacama	0	3	6	9
	Coquimbo	2	6	7	15
	Valparaíso	9	15	14	38
	O'Higgins	2	14	17	33
	Maule	2	15	13	30
	Biobio	9	12	12	33
	La Araucanía	1	16	14	31
	Los Lagos	2	9	19	30
	Aysen	0	2	6	8
	Magallanes	0	2	6	8
	Metropolitana	36	13	3	52
	Los Ríos	1	7	4	12
	Arica y Parinacota	0	1	3	4
	Nuble	2	6	12	20
	Chile	68	124	147	339

Table 2: Total populations for each region for each strata (urban, rural) in our design.

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Region	Municipalities
Tarapaca	Iquique, Alto Hospicio, Pozo Almonte, Camina, Colchane, Huara, Pica
Antofagasta	Antofagasta, Calama, Tocopilla, Mejillones, Sierra Gorda, Taltal, Ollague, San Pedro de Atacama, Maria Elena
Atacama	Copiapo, Caldera, Vallenar, Tierra Amarilla, Chanaral, Diego de Almagro, Alto del Carmen, Freirina, Huasco
Coquimbo	La Serena, Coquimbo, Vicuna, Illapel, Los Vilos, Salamanca, Ovalle, Monte Patria, Andacollo, La Higuera, Paiguano, Canela, Combarbala, Punitaqui, Rio Hurtado.
Valparaíso	Valparaiso, Concon, Calera, La Cruz, San Antonio, Cartagena, San Felipe, Quilpue, Villa Alemana, Casablanca, Puchuncavi, Quintero, Vina del Mar, Los Andes, San Esteban, La Ligua, Cabildo, Quillota, Hijuelas, Nogales, Llaillay, Putaendo, Limache, Olmue, Juan Fernandez, Isla de Pascua, Calle Larga, Rinconada, Papudo, Petorca, Zapallar, Algarrobo, El Quisco, El Tabo, Santo Domingo, Catemu, Panquehue, Santa Maria
O'Higgins	Rancagua, Graneros, Coltauco, Donihue, Las Cabras, Machali, Mostazal, Pichidegua, Rengo, Requinoa, San Vicente, Pichilemu, San Fernando, Chimbarongo, Nancagua, Santa Cruz, Codegua, Coinco, Malloa, Olivar, Peumo, Quinta de Tilcoco, La Estrella, Litueche, Marchihue, Navidad, Paredones, Chepica, Lolol, Palmilla, Peralillo, Placilla, Pumanque
Maule	Talca, Curico, Constitucion, Maule, San Clemente, Cauquenes, Molina, Sagrada Familia, Teno, Linares, Colbun, Longavi, Parral, Retiro, San Javier, Villa Alegre, Yerbas Buenas Curepto, Empedrado, Pelarco, Pencahue, Rio Claro, San Rafael, Chanco, Pelluhue, Hualane, Licanten, Rauco, Romeral, Vichuquen
Biobio	Concepcion, Coronel, Chiguayante, Lota, Penco, San Pedro de la Paz, Talcahuano, Tome, Hualpen, Hualqui, Lebu, Arauco, Canete, Curanilahue, Los Alamos, Los Angeles, Cabrero, Laja, Mulchen, Nacimiento, Yumbel Florida, Santa Juana, Contulmo, Tirua, Antuco, Negrete, Quilaco, Quilleco, San Rosendo, Santa Barbara, Tucapel, Alto Biobio
La Araucanía	Temuco, Carahue, Cunco, Freire, Lautaro, Loncoche, Nueva Imperial, Padre Las Casas, Pitrufquen, Pucon, Vilcun, Villarrica, Angol, Collipulli, Curacautin, Traiguen, Victoria, Curarrehue, Galvarino, Gorbea, Melipeuco, Perquenco, Saavedra, Teodoro Schmidt, Tolten, Ercilla, Lonquimay, Los Sauces, Lumaco, Puren, Renaico
Los Lagos	Puerto Montt, Osorno, Calbuco, Frutillar, Los Muermos, Llanquihue, Puerto Varas, Castro, Ancud, Quellon, Purranque, Cochamo, Fresia, Maullin, Chonchi, Curaco de Velez, Dalcahue, Puqueldon, Queilen, Quemchi, Quinchao, Puerto Octay, Puyehue, Rio Negro, San Juan de la Costa, San Pablo, Chaiten, Futaleufu, Hualaihue, Palena
Aysen	Coyhaique, Aysén Lago Verde, Cisnes, Guaitecas, Cochrane, Chile Chico, Rio Ibanez
Magallanes	Punta Arenas, Natales Laguna Blanca, San Gregorio, Cabo de Hornos, Porvenir, Primavera, To
Metropolitana	Santiago,Cerrillos, Cerro Navia, Conchali, El Bosque, Estacion Central, Huechuraba, Independencia, La Cisterna, La Florida, La Granja, La Pintana, La Reina, Las Condes, Lo Barnechea, Lo Espejo, Lo Prado, Macul, Maipu, Nunoa, Pedro Aguirre Cerda, Penalolen, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado,Penaflor, Pirque, San Jose de Maipo, Colina, Lampa, Tiltil, Buin, Calera de Tango, Paine, Melipilla, Curacavi, Talagante, El Monte, Isla de Maipo, Alhue, Maria Pinto, San Pedro
Los Ríos	Valdivia, Lanco, Los Lagos, Mariquina, Paillaco, Panguipulli, La Union, Rio Bueno, Corral, Mafil, Futrono, Lago Ranco
Arica y Parinacota	Arica Camarones, Putre, General Lagos
Nuble	Chillan, Chillan Viejo, Bulnes, Quillon, San Ignacio, Yungay, San Carlos, Coihueco, El Carmen, Pemuco, Pinto, Quirihue, Cobquecura, . Coelemu, Ninhue, Portezuelo, Ranquil, Treguaco, Niquen, San Fabian

Table 3: Names of all urban (red), rural (blue) and excluded (black) municipalities of each region.

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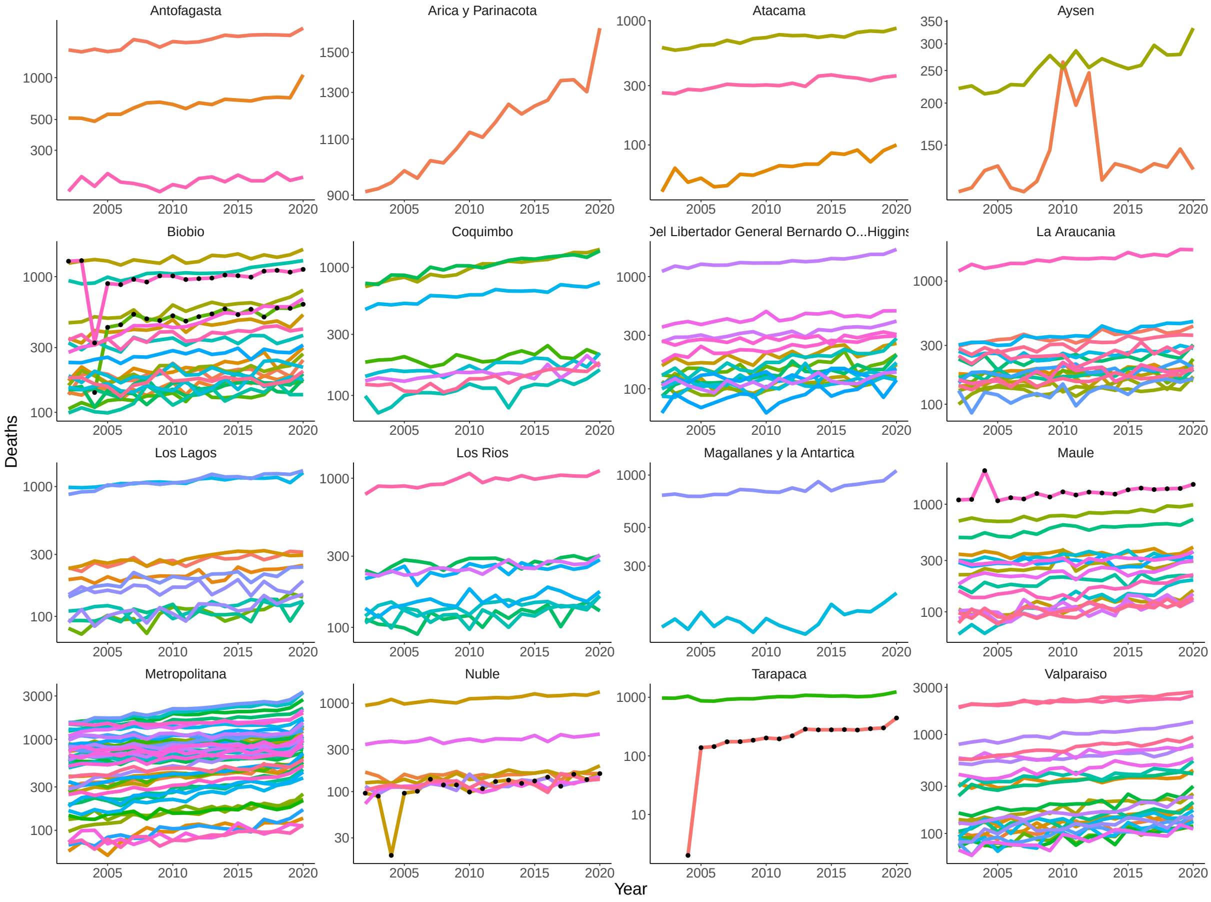

Figure 1: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring years (Talcahuano, Hualpén, Diego de Almagro, Talca, Alto Hospicio, Chillán Viejo).

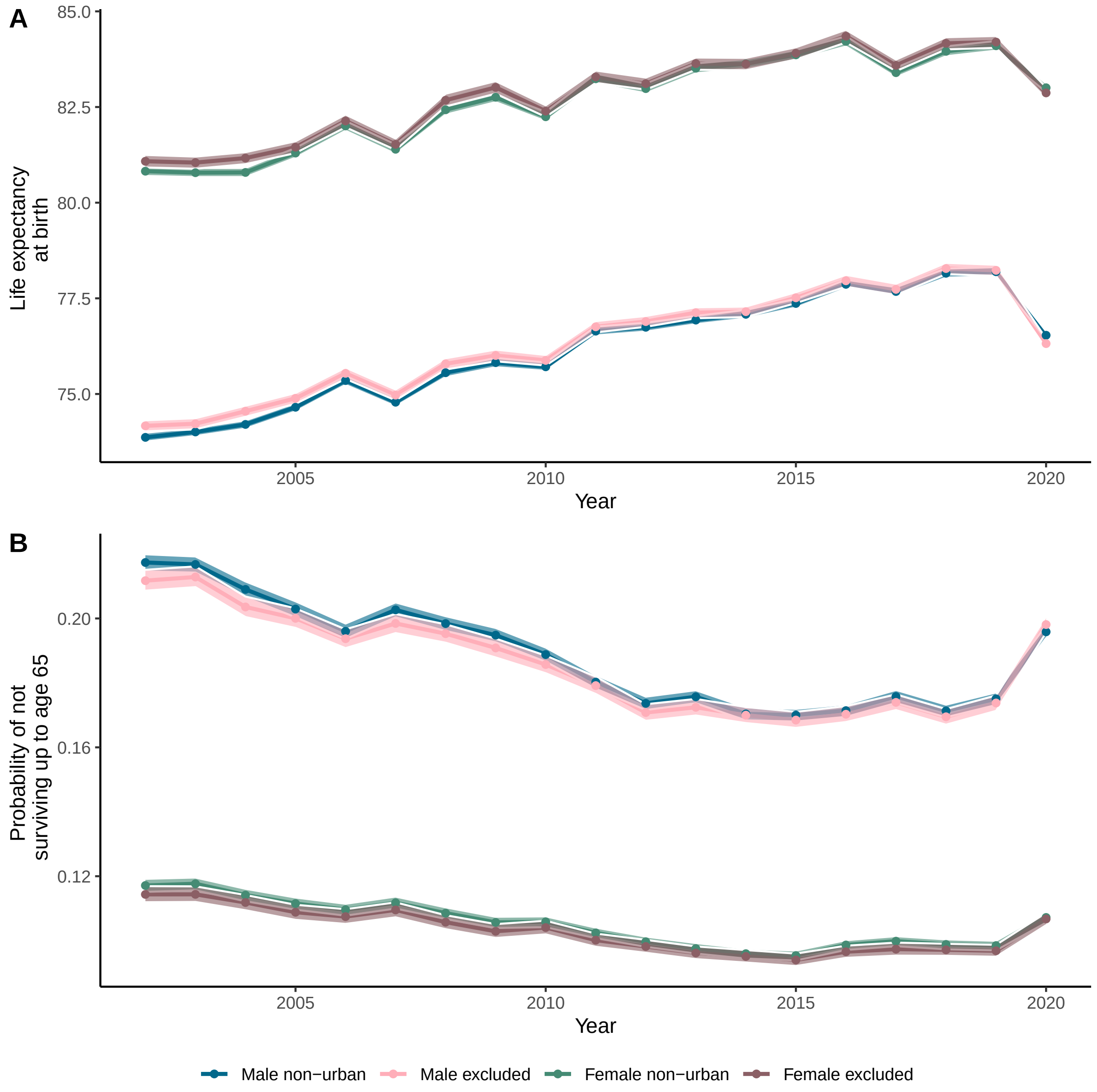

Figure 2: **A**. Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B**. Same as **A**, but with likelihood of dying before reaching 65.

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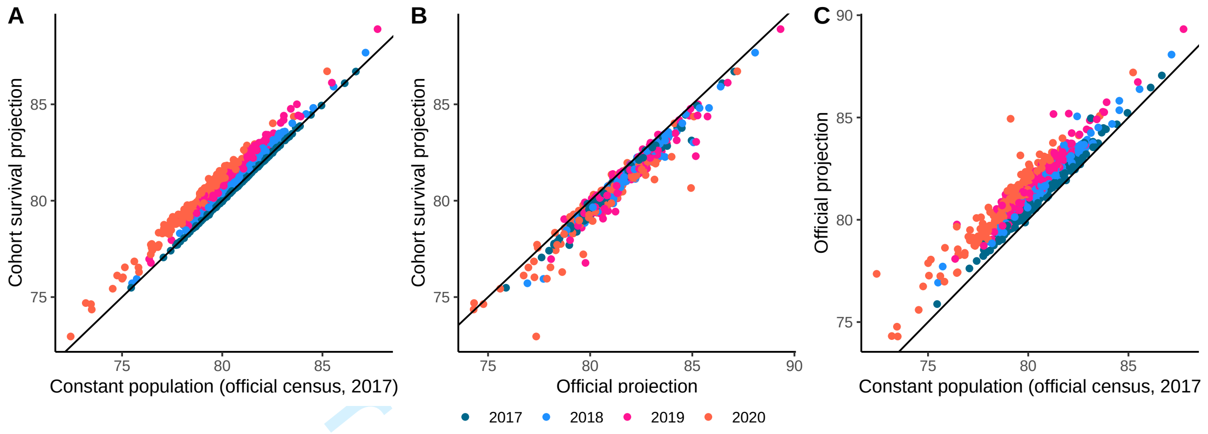

Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival projection. In **C** we compare official projection with the one that has constant population.

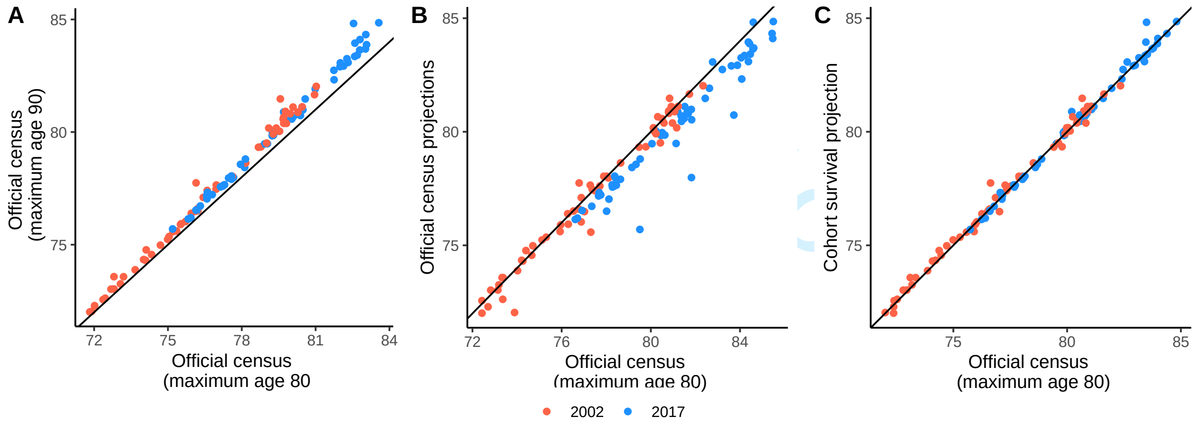

Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with official projections in that year. We note that discrepancies become more significant in year 2017, indicating the need for an alternative methodology. In **C** we compare official census (80 as cutoff age) with our cohort survival projection method. They are in close agreement, as they are both based on official census data, and not projections.

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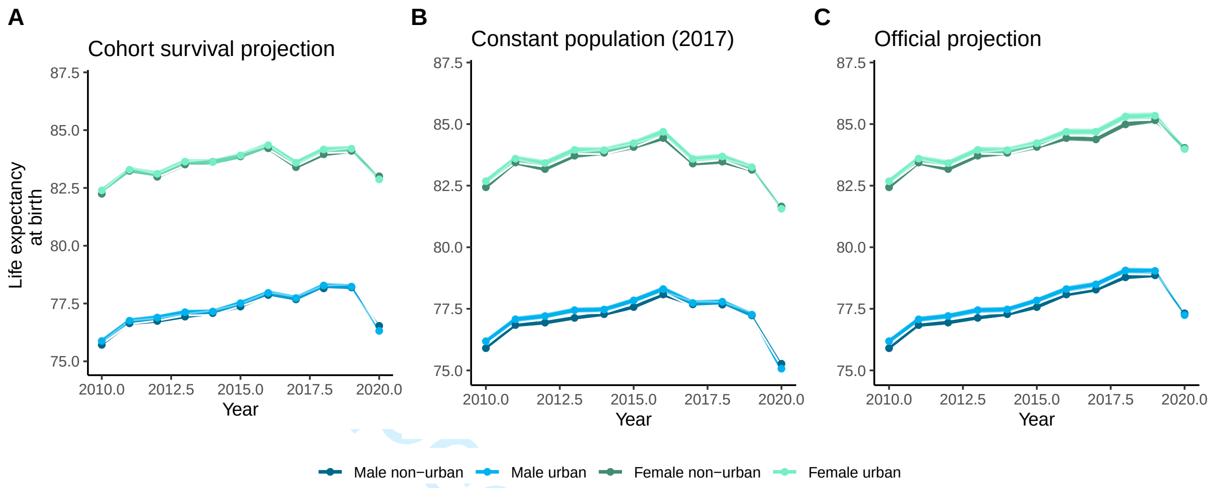

Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with **A**.

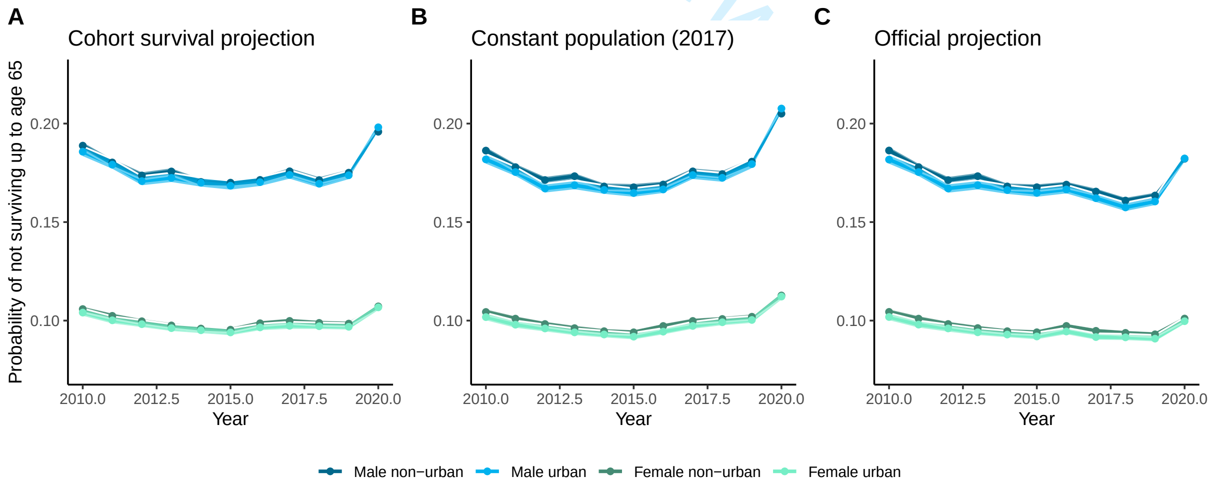

Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with **A**.

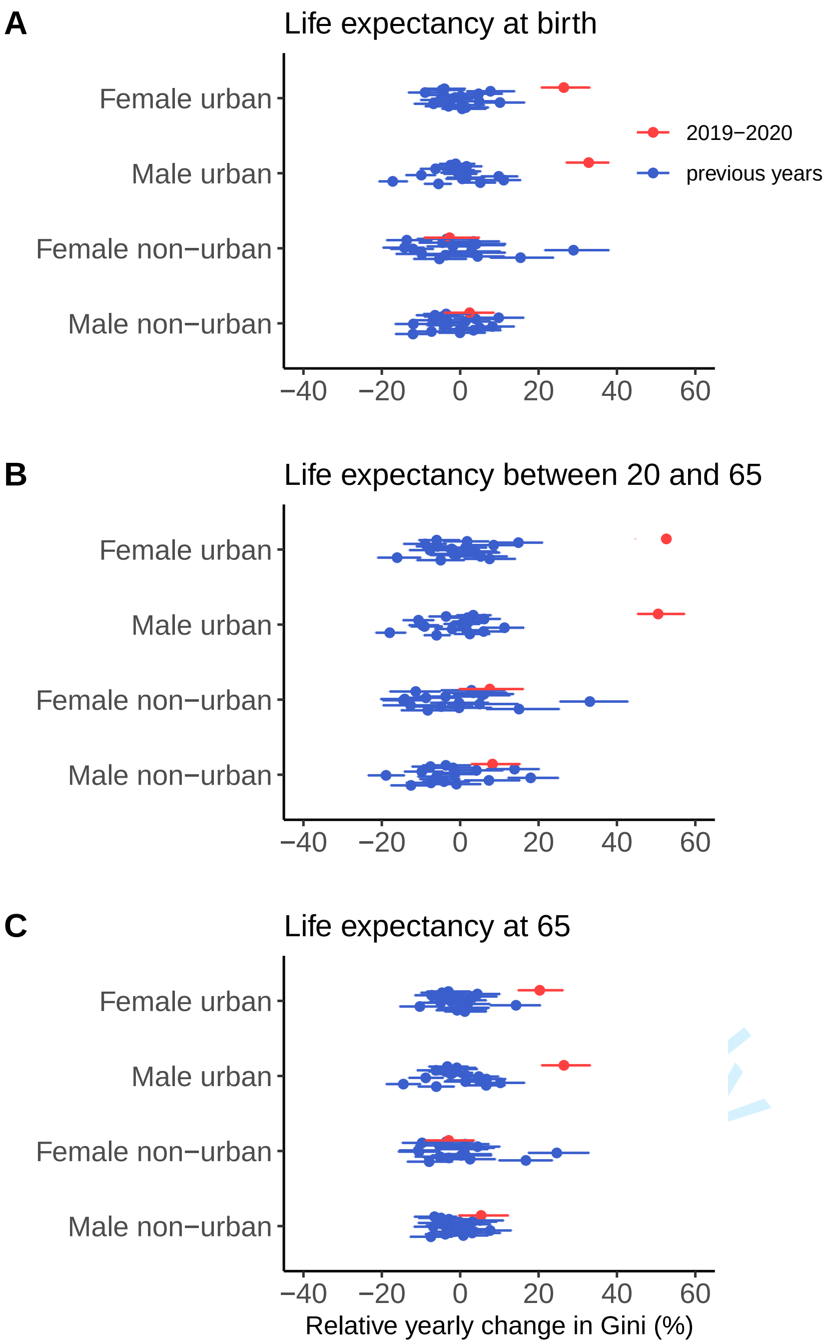

Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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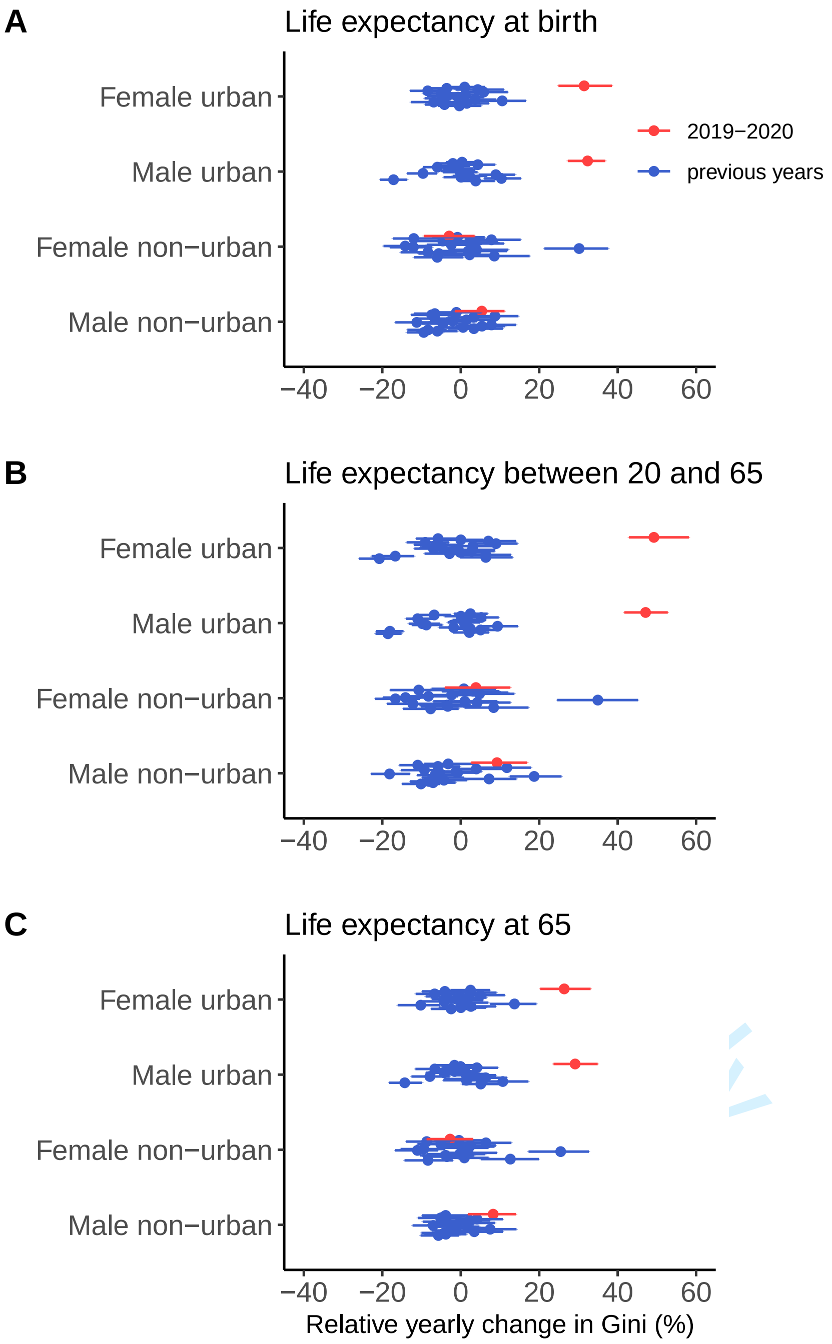

Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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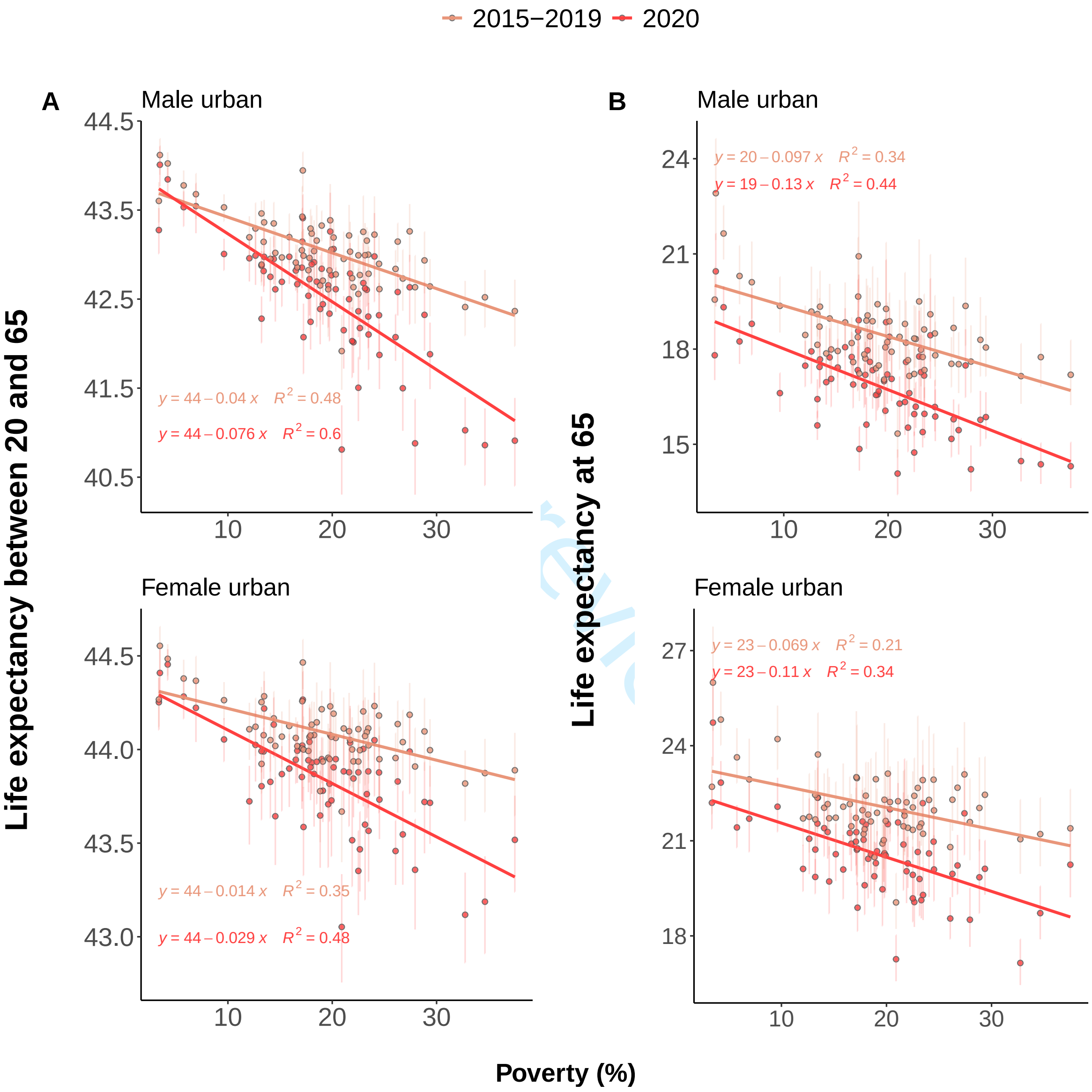

Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019 and 2020, and may be compared with Exhibit 4 in the main text.

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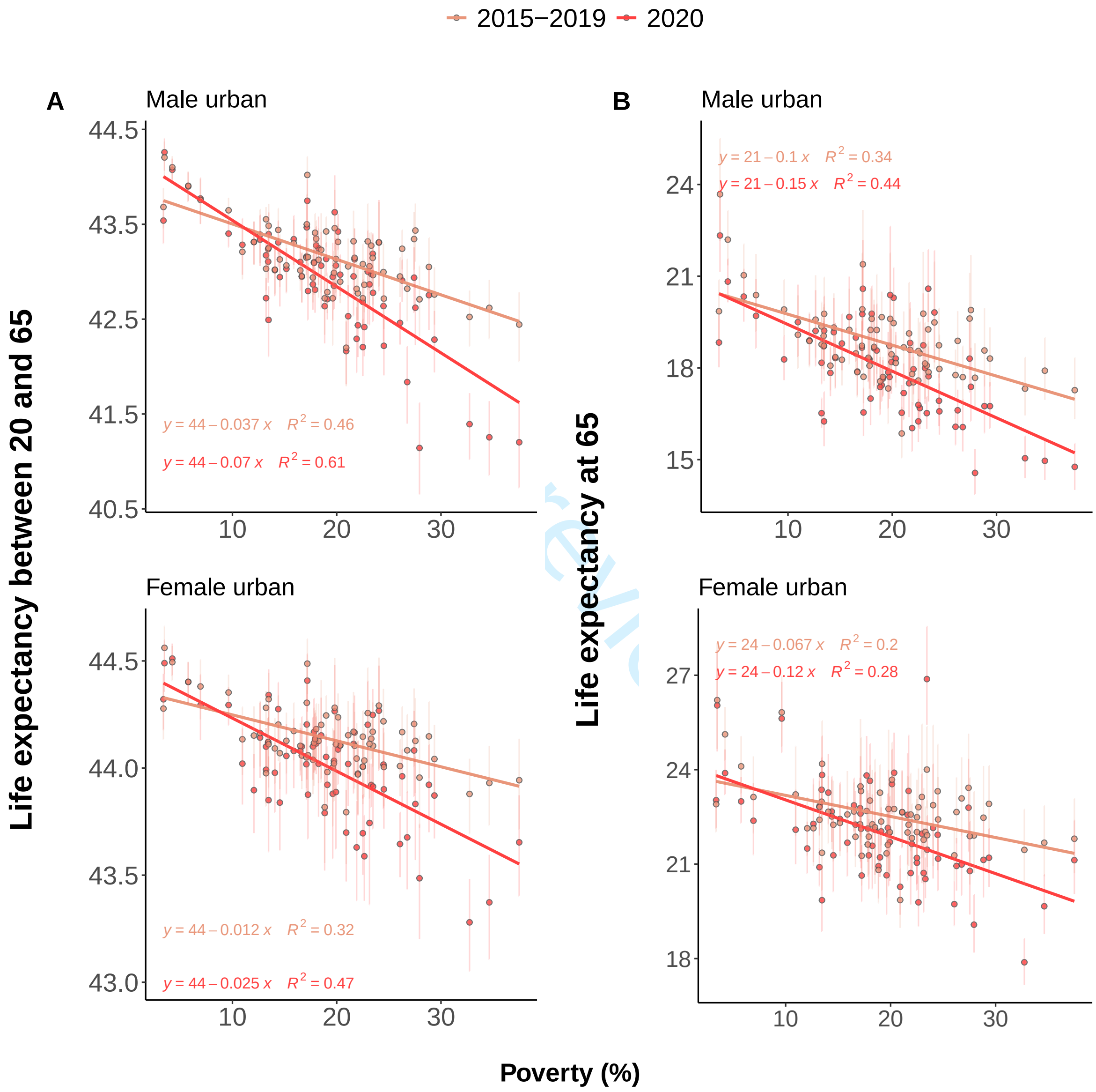

Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

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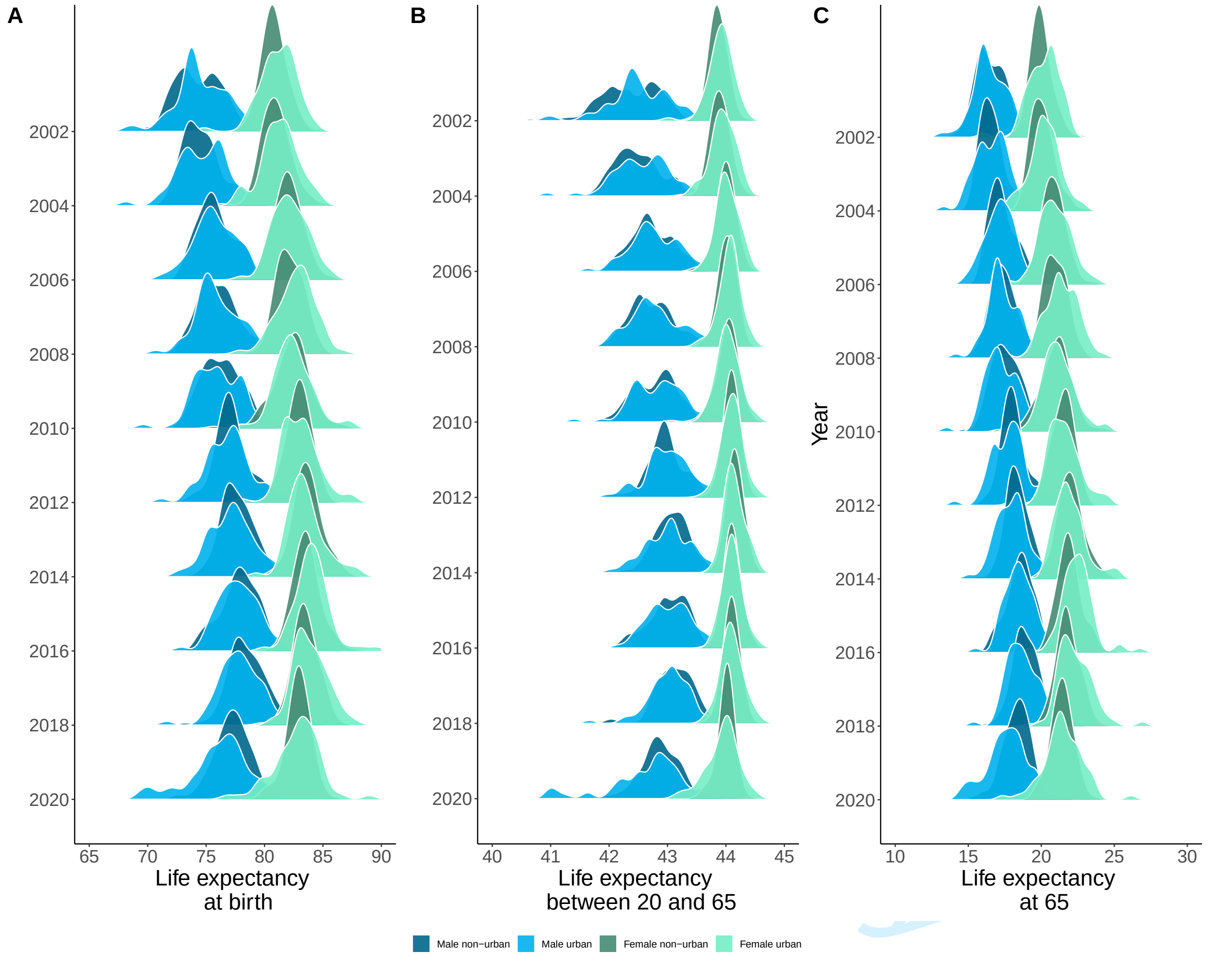

Figure 11: Histograms of life expectancies over time, for male/female and urban/non-urban settings. These histograms are made by taking each combination of gender as municipality as a sample. We note that a left tail appears during 2020 for urban municipalities

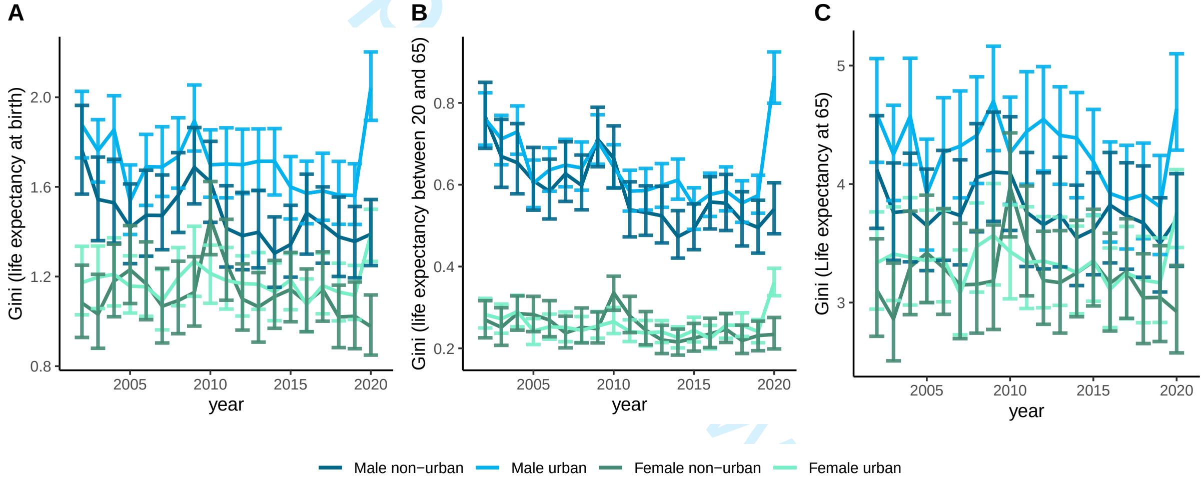

Figure 12: Time evolution of Gini. This plot supplements Exhibit 3, where only year-to-year differences are shown. Bars represent 95% credible intervals.

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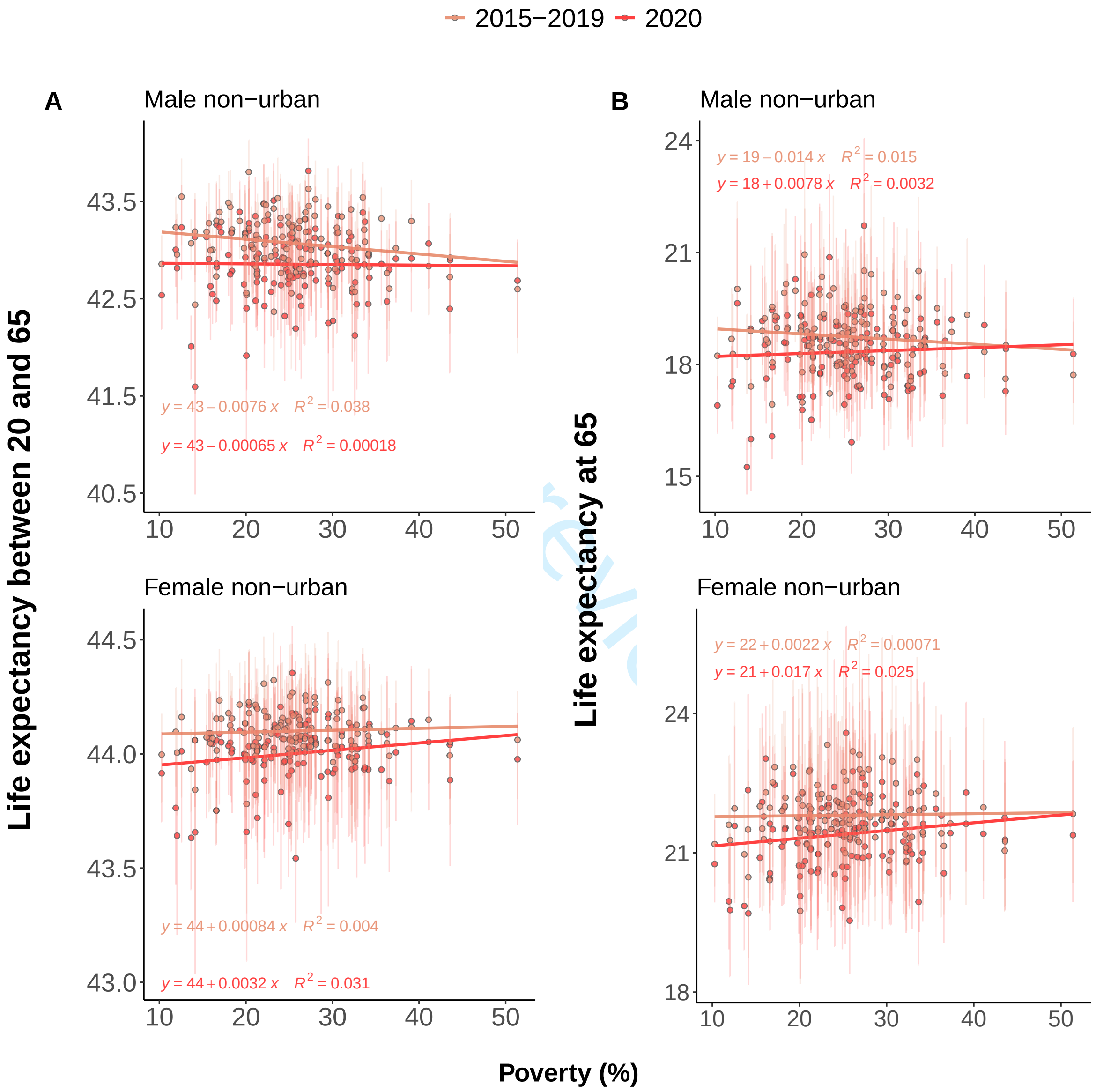

Figure 13: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

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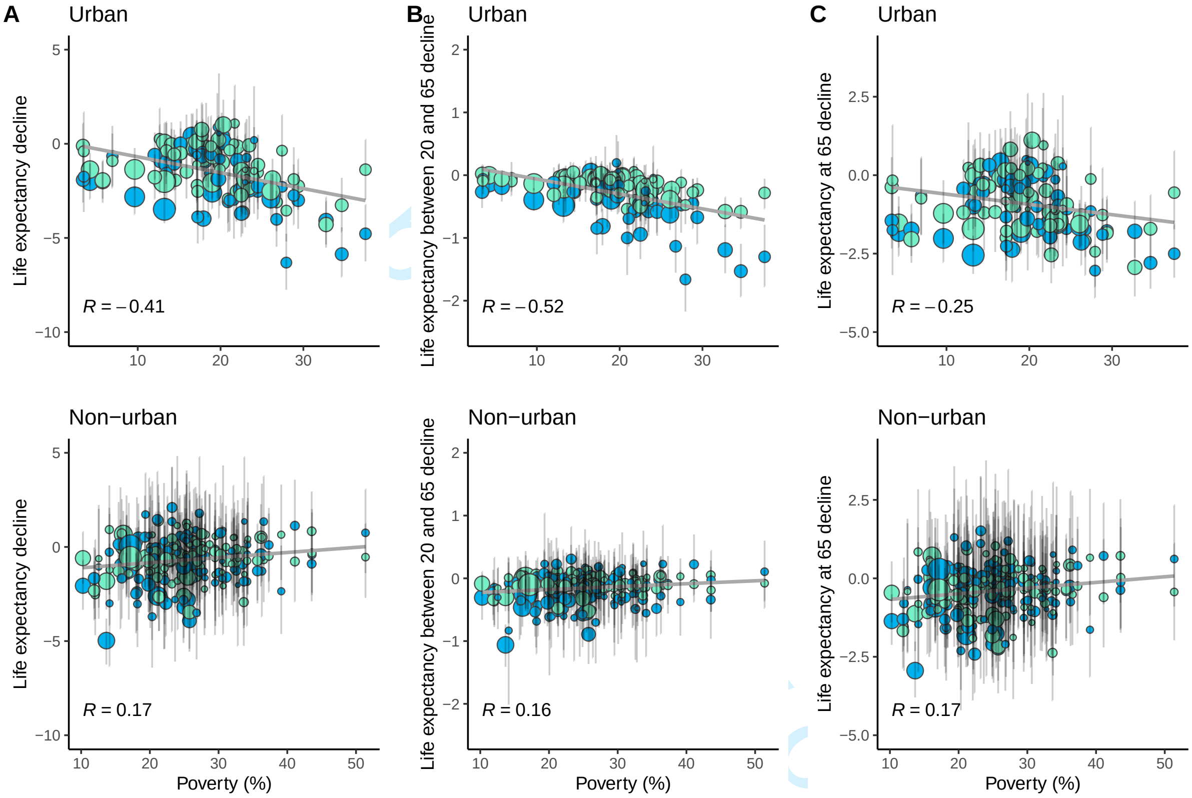
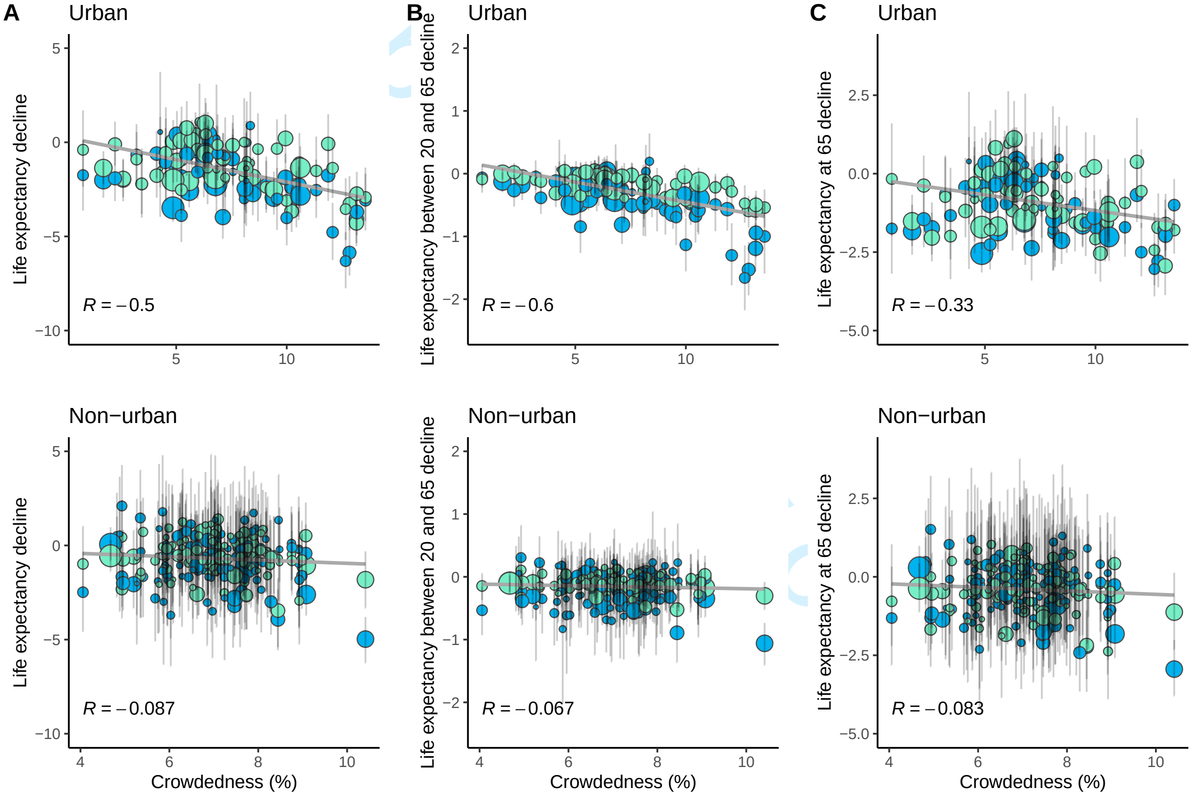


Figure 14: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and second row, respectively. A strong effect appears in urban setups, and the correlation is stronger in for life expectancy between 20 and 65.

Figure 15: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in a crowded home. Each dot is a municipality, separated by gender(colors) Urban and non-urban municipalities are shown in first and second row, respectively.



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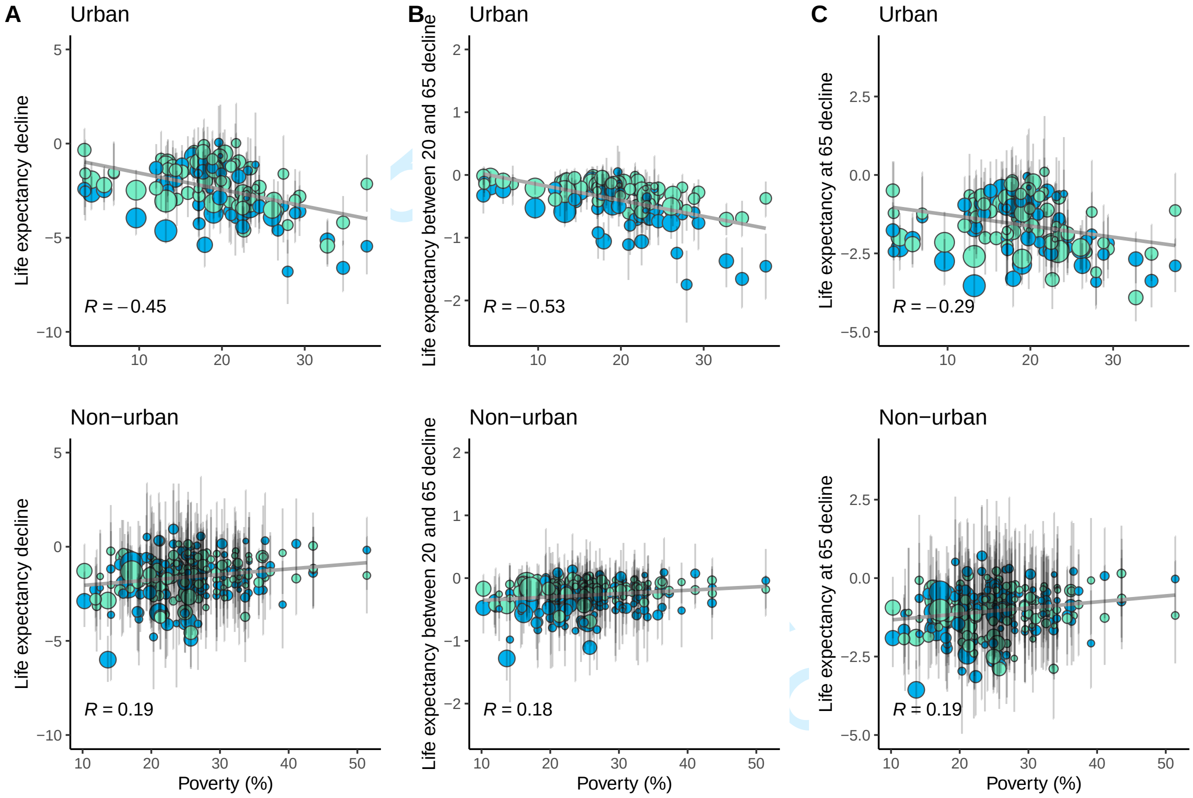

Figure 16: Same as 14 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

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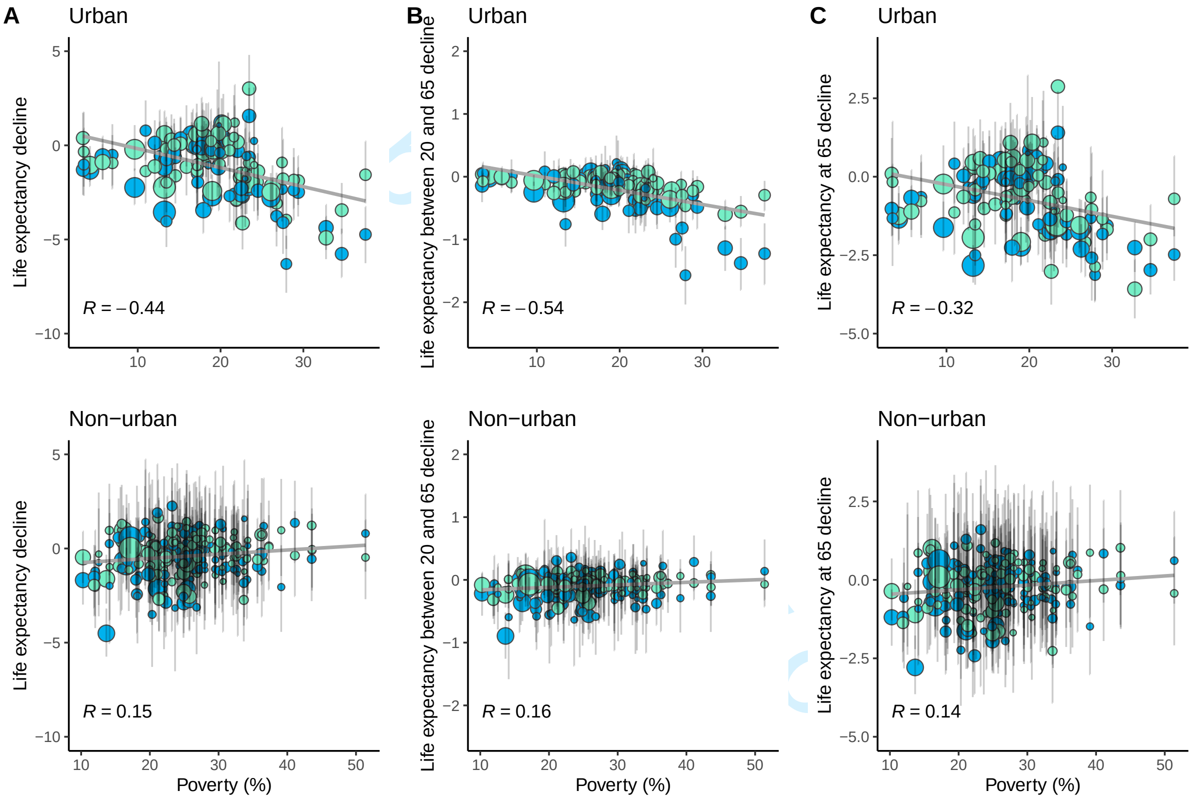

Figure 17: Same as 14 but with population estimates given by official projections.

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*8*
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	7-9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	7-9
		(*c*) Explain how missing data were addressed	7-8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	7-8
		(*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	NA
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	NA
Outcome data	15*	Report numbers of outcome events or summary measures	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-8
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-11
Discussion			
Key results	18	Summarise key results with reference to study objectives	9-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-11
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Title: The unequal impact of the COVID-19 pandemic in 2020 on life expectancy across urban areas in Chile: A cross-sectional demographic study.

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Abstract (205 words):

Objectives: To quantify the impact of the COVID-19 pandemic on life expectancy in Chile categorized by rural and urban, and to correlate life expectancy changes with socioeconomic factors at the municipal level.

Design: Retrospective cross-sectional demographic analysis using aggregated data.

Setting: Vital and demographic statistics from the national institute of statistics and department of vital statistics of ministry of health.

Participants: Aggregated national all-cause death data stratified by year during the 2000-2020 period, sex, and municipality.

Main Outcome measures: Stratified mortality rates using a Bayesian methodology. With this, we assessed the unequal impact of the pandemic in 2020 on life expectancy across Chilean municipalities for men and women and analyzed previous mortality trends since 2010.

Results: Life expectancy declined for both men and women in 2020. Urban areas were the most affected, with males losing 1.89 years and females 1.33 years in 2020. The strength of the decline in life expectancy correlated positively with indicators of social deprivation and poverty. Also, inequality in life expectancy between municipalities increased, largely due to excess mortality among the working-age population in socially disadvantaged municipalities.

Conclusions: Not only do people in poorer areas live shorter lives, they also have been substantially more affected by the COVID-19 pandemic, leading to increased population health

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inequalities. Quantifying the impact of the COVID-19 pandemic on life expectancy provides a more comprehensive picture of the toll.

Keywords: COVID-19, Latin America, Mortality, Life expectancy, Health Inequalities

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Strengths and limitations

- First study to analyze changes in life expectancy in Chile with small-area resolution.
- We applied a hierarchical Bayesian methodology to estimate life expectancies in the past 20 years.
- The study shows associations between life expectancy and measures of social disadvantage in the context of the pandemic.
- The study is limited by the small number of death counts in some areas, which increases uncertainty around estimates.
- Data quality may be a limitation for the study, which we try to overcome with the Bayesian estimation of mortality.

Main Text

Introduction

Most Latin American countries experienced substantial progress in reducing premature mortality while increasing health standards over the last century and into the first fifteen years of the twenty-first century.[1,2] But this progress has been reversed, as Latin American countries have been severely affected by the COVID-19 pandemic.[3] The region became the hotspot of the pandemic in June 2020 and by March 2022 more than one and a half million COVID-19 deaths have been reported.[4]

After decades of sustained improvements in life expectancy, leading to levels comparable to low mortality countries, Chile experienced losses in this indicator in 2020 due to increased excess mortality during the COVID-19 pandemic (11 months for women and 1.3 years among men).[5] While national figures are important and informative, they conceal heterogeneity at the subnational level, which can be substantial. Emerging evidence from Latin American countries suggests that the COVID-19 pandemic has disproportionately affected disadvantaged groups with low socioeconomic status with large regional variation.[6-10]In the context of Santiago, Chile's capital, the observed worse outcomes in more deprived areas were explained by the combination of lower access to healthcare, poorer baseline health status of individuals, higher exposure to Sars-COV2 because of a reduced compliance with shelter-in-place orders (in turn, reflecting the inability to work from home), and by an ineffective epidemic surveillance system whose resources were predominantly allocated to more affluent areas, hampering early containment efforts.[6]

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One key question is how the interplay of social and demographic factors at a more granular geographic scale affected life expectancy during the first year of the pandemic. Focusing on differences in mortality by age, sex, social deprivation and urbanity, we aimed at exploring two main hypotheses: 1)life expectancy has been affected differently for females and males by urbanity status. Since COVID-19 first waves concentrated their impact on urban centers in Chile,[6] we expect that declines of life expectancy were larger in urban areas. Also, since COVID-19 outcomes are typically worse among males at the national level,[11,12] we expect larger drops in life expectancy among males in urban areas. 2)Larger life-expectancy losses were more predominant in socially deprived areas. This hypothesis stems from the known negative correlation between poverty and life expectancy.[13] But because of the intricate relation between COVID-19 deaths by age and social deprivation, it is not straightforward to determine whether this correlation became stronger during the pandemic. In support of this hypothesis, recent research in Chile's Capital showed a strong negative correlation between excess deaths and socioeconomic status, and that this correlation was particularly stark among younger age-groups but eventually evened out for the elderly.[6] Since life expectancy more strongly weights mortality at younger ages, it is likely that excess young-age mortality may have increased inequality in life expectancy. Alternatively, since death rates increased exponentially with age and losses in life expectancy in low mortality countries have been attributed mostly to mortality above age 60,[5] it is likely that the pandemic in 2020 was such a

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strong shock that excess mortality differentials decreased, leading to reducing inequalities between municipalities.

This article contributes towards a more comprehensive understanding of the COVID-19 pandemic's burden on population health by estimating life expectancy across Chilean municipalities by sex using a powerful Bayesian methodology.[14] We contextualize our results with past trends of progress and disparities in life expectancy, and comment on the the relevance of acknowledging such persisting disparities in the design of social security mechanisms. Our study is a step towards explaining the varied impacts of the pandemic by analyzing trends in life expectancy over age at a more granular level and by correlating life expectancy losses with indicators of poverty in Chile.

Study Data and Methods

Data

We used data on births and deaths by age, sex and municipality from publicly available vital statistics.[15] These data were complemented with official population counts by age (single years of age grom 0 to 89 and collapsed in 90+), sex and municipality from the 2002 and 2017 censuses available from the National Institute of Statistics (INE).[16] We also used official population projections between 2002 and 2020 centered at the 2017 census.[17] Unlike censuses themselves,

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these projections collapsed all ages greater than 80 in one single group. We only observed minor changes in our estimates based on whether the open ended interval started at 80 or 90, but we did observe that life expectancy estimates based on 2017 projections were substantially higher than the ones based on the 2017 census. We explain this by a possible inadequacy of the official projection for later years. Because of this reason, we considered two alternative population estimates for 2017 onwards. The first one assumes that population counts remain fixed for years 2018,2019 and 2020. In the second one, we projected forward the population using the cohort component method[18] with 2017 as baseline assuming zero migration. We also used census data to classify municipalities as urban or non-urban following,[19] if the following two conditions hold: i) population density greater than 70 people per square kilometer, and ii) the proportion of people living in an urban environment is greater than 88%. Chile is made up of 366 municipalities and according to this criteria, 35% are qualified as urban, making up for the 65% of the population (17539805, as per the 2017 Census). See Supplementary Tables 1-3 for details. .Data on poverty and crowdedness were taken from the CASEN survey by the Chilean Ministry of Social Development and Family.[20] CASEN is the most comprehensive official poverty survey available in Chile. For poverty, we used the 'multidimensional poverty' indicator. In CASEN, a household is defined to suffer from multidimensional poverty if it accumulates 22.5% of deprivation according to a weighted score that takes into fifteen items from income, access to healthcare, labor, social security, housing and social cohesion. Likewise, a household is considered crowded if there are 2,5 or more people per room.

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Mortality estimation

We performed mortality analyses at the spatial resolution of municipalities, since these are the finest spatial units at which age and gender specific mortality data are available, as well as demographic data and covariates (poverty, crowdedness) are. By considering municipalities as units we are able to investigate the variation of the resulting distribution of mortality and its relation with our measured covariates (age, urbanity status, poverty). Age specific death rates for each municipality by sex were estimated implementing a recently developed methodology[14] based on a hierarchical Bayesian model[21] using population and death counts. There are two main advantages to this Bayesian methodology:, first, the fact that municipality specific rates are assumed to be samples from a population with global parameters enables the sharing of information sharing between municipalities, helping to smooth out the noisy estimates that would otherwise be obtained if we relied only on empirical counts. This is important because of the increased likelihood of low death counts on each strata in small municipalities. Second, by appealing to the Bayesian methodology we immediately obtain credible intervals for each of our estimates.

Life tables

Life tables were calculated using the age specific death rates estimated in the Bayesian procedure following standard techniques.[18]

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From these, period life expectancy at birth, temporary life expectancy between ages 20 and 65, and remaining life expectancy at age 65 were obtained. Life expectancy at birth refers to the average years a cohort of newborns is expected to live given the current mortality conditions. Similarly, life expectancy at age 65 refers to the average years individuals aged 65 are expected to live if they were to experience the current mortality conditions throughout their lives. Given the emerging evidence about how younger age groups below age 65 have also been affected by the pandemic in the context of Chile, we constructed a measure to capture average longevity over working ages through temporary life expectancy. Temporary life expectancy between ages 20 and 65 refers to the average years lived between these ages given prevalent mortality conditions.[22] For example, if no one were to die between these ages, then the temporary life expectancy would be the full 45 years. To complement our analysis we also consider the probability of not reaching age 65 as an indicator of premature mortality.

Measuring heterogeneity

We leverage the availability of life expectancy estimates at the municipality level to conceive a fictitious population where each municipality is a sample. We quantify the heterogeneity of this population through the Gini coefficient.[23] The Gini coefficient is a standard indicator of inequality employed in social sciences. In the context of this paper, the Gini coefficient expresses the degree of inequality in life expectancy across municipalities. With our methodology, we can seamlessly quantify temporal changes of the Gini

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for different strata (male/female, urban/non-urban) and report credible intervals.

Patient and Public Involvement

No patients were involved in this paper, all the analyses are based on aggregated data.

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Results

Trends in life expectancy at birth and survivorship below age 65.

Men and women from both urban and non-urban areas experienced steady increases in life expectancy at birth from 2010 to 2019. Women showed higher life expectancy at birth than men in all groups. In contrast, higher mortality during 2020 led to sharp decreases in life expectancy at birth (Figure 1). Life expectancy among men in urban and non-urban areas declined by 1.89 (1.68,2.09) and 1.66 (1.50,1.80) years, respectively. Among women, life expectancy losses were 1.33 (1.11,1.55) and 1.10 (0.92,1.28) years, respectively. The magnitude of the decline from 2019 to 2020 offset most gains in life expectancy experienced in the last decade, especially in urban areas. In fact, 68% of the municipalities analyzed ended up with lower life expectancy than in 2015, and this number rose to 75% in urban municipalities. In terms of individuals, 76% (non-urban) and 78% (urban) of the population lived in a municipality that faced a decline in life expectancy compared to 2015.

Declines in the probability of surviving to age 65 (Figure 2) between 2019 and 2020 indicate that changes in life expectancy cannot be fully attributed to increased mortality in older age groups only. While mortality above age 65 has been documented as one of the main contributors to declines in life expectancy internationally, substantial increases in mortality below age 65 are apparent in our results, especially among men in urban areas.

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Changes in disparities in life expectancy during the COVID-19 pandemic in 2020

Figure 3 shows the time evolution of the inequality in life expectancies across municipalities, and shows the striking impact of COVID-19 on this quantity. Inequality increased in urban areas from 2019 to 2020 with changes oscillating around 25%, a rate not seen in the recent past. The magnitude of increase is much larger in men and women's life expectancy between ages 20 and 65 from urban areas (50.9% and 50.6% for men and women respectively). Contrarily, in non-urban areas we do not observe changes deviating significantly from usual year-to-year fluctuations. Altogether, these results indicate not only that mortality during 2020 became more unequal, but that this inequality was driven mostly by the younger age group.

Histograms in Figure 3 suggest that the abrupt increase in inequality during 2020 can be attributed to heavier left tails of the life expectancy distribution, indicating an increase in the amount of municipalities with a much lower-than-average life expectancy. To better understand the factors driving this spike in inequality, we investigated how declines in life expectancy during 2020 correlated with social deprivation indicators including poverty and crowdedness focusing only on mortality above age 20 across urban areas. Figure 4 shows the negative association between poverty and life expectancy between age 20 ang 65 and life expectancy at age 65. To underscore how the relationship changed in the course of 2020, we stratified the results juxtaposing the previous five years (2015-19) with 2019-20. Results show a strong historical negative correlation between life expectancies in both age groups, sexes and poverty levels. Males in the top poverty decile have a 4.39 expectancy lower life expectancy than in the bottom decile. They also live on average 0.92 less years between 20 and 65, and 2.22 from 65 onwards. For females, these numbers are 2.51, 0.31 and 1.55 years. During 2020, the slope became more negative, suggesting that those municipalities with higher levels of poverty experienced greater losses in life expectancy. This dependency was stronger in the younger age group.

In contrast, while life expectancy at 65 declined during 2020, this decline was less unequal over the poverty gradient, consistent with the hypothesis that this group contributed less to inequality in changes in life expectancy. To formalize these observations, we performed regression analyses to model the interactions between year and poverty level through varying intercepts and slopes. We only found significant changes in slope for average years lived between 20 and 65. For males, this translated into an additional difference of 0.78 years between the highest and lowest poverty deciles (p=0). For females, this difference was 0.30 (p<0.001).

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Discussion

Urban areas that are exposed to higher poverty or social disadvantages experienced larger losses in life expectancy during the COVID-19 crisis in 2020 in Chile. Our results reveal that losses were unevenly shared across municipalities, over age, and by sex, leading to increasing inequality in life expectancy across regions in Chile. Moreover, consistent with previous research on increased mortality at younger ages in 2020 in deprived municipalities in Chile's capital,[6] our research shows that working age mortality was one of the main drivers of increasing inequality in life expectancy across Chile.

Analysis of life expectancy in 2020 compared with the previous five years (2015-19) show that poorer urban municipalities suffered a double burden. Not only did they show lower levels of life expectancy but they also experienced greater losses in life expectancy. This is consistent with previous research documenting larger mortality increases for the lower educated groups in Chile's capital.[24] Furthermore, when we disaggregate by age groups, we observe that the association between life expectancy for working age individuals (between ages 20 and 65) and levels of poverty became stronger compared to previous years. This is a surprising finding given that previous evidence had documented a positive association between income and life expectancy at retirement.[25] This suggests that even if the burden of mortality during the COVID-19 crisis has been concentrated at older ages,[26] contributing substantially to life expectancy declines during 2020,[27] inequalities in life expectancy

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were largely driven by increased mortality in working ages at higher levels of poverty. A potential explanation is that the working age population's availability to work from home and be less exposed to heightened risk of COVID-19 and its consequences varies across poverty levels. Deprived populations in Chile's capital experienced higher fatality rates as a consequence of worse baseline individual health status and to an overwhelmed healthcare system.[6] Similarly, evidence from the US suggests that those individuals with less availability to work from home had higher death rates compared to those that could afford working from home in 2020.[28]

An open question is whether this sudden increase in inequality amounts to a shock that will be followed by a recovery to pre-pandemic levels, or whether these changes will persist in the long term. Beyond the immediate increase in premature mortality, this is relevant because failing to acknowledge inequalities in mortality may compromise the progressiveness and actuarial fairness of social security and public pension systems in the long term,[29,30] which could be translated into higher mortality in the future. Similarly, the scars left by the pandemic, including a weak health system, may increase mortality from multiple causes of death. For example, postponed cancer treatments and failure to detect other chronic degenerative diseases timely may lead to lower levels of life expectancy in the long term than it was projected. This highlights the need for accurate and timely data on other causes of death. Future analysis should focus on analyzing the consequences of the COVID-19 pandemic, including multiple causes of death and diseases to study the direct impacts from COVID-19 mortality as well as the

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indirect impacts through other pathways of diseases and conditions.[31] Our research, in this sense, provides a first outlook by focusing on all-cause mortality.

As shown by our results, the case of Chile underscores the dire widening of an already large mortality gap between those living in deprived conditions and those living with higher income during the COVID-19 crisis. Evidence shows that the health consequences of external shocks such a pandemic or an economic crisis are not spread equally across social deprivation levels.[32] The COVID-19 pandemic reminds us of the ever-present risk of such events, whose cumulative impact may partially explain the ever-existing gaps in mortality. Therefore, the way that this crisis has exposed the vulnerabilities of socially deprived populations is a call to challenge the monolithic view of a country’s demographics in the design of social security systems. New strategies incorporating a public health perspective that considers widening inequalities should be implemented to minimize the impacts of the COVID-19 pandemic on the health status of the Chilean population both immediately and in the long term.

Limitations

This study had several limitations. First, while Chile’s vital registration is one of the most reliable in Latin America, there are likely to be inaccuracies in mortality registration due to age misreporting and coverage across municipalities, as well as systematic age overstatement.[33] Delays in recording deaths may lead

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to incompleteness issues especially in urban areas. Our results on life expectancy declines and mortality inequalities may be considered a lower bound because of these issues. The effect of systematic age overstatement is likely to affect our results too. However, there is no information on what the age pattern of overstatement is during the pandemic. To mitigate these inaccuracies and their effects on our life expectancy estimates, we used a hierarchical Bayesian model that helped to retrieve a reasonable mortality profile across regions. Another limitation is that because of the low number of deaths observed in some municipalities, the degree of uncertainty around the estimates was very high, not allowing us to include them in our analysis with confidence. We excluded municipalities by sex with less than 16,000 people (as per the 2017 census), as we observed that life expectancy estimates were unstable even with our adopted Bayesian methodology. However, we grouped them together and reproduced all results to avoid systematic exclusion. Results were consistent and are shown in Supplementary Figure 2. Almost all of these were all non-urban municipalities. Some other six municipalities were excluded for the 2004 year based on a visual inspection of mortality trends that were clearly indicative of coding errors in the mortality database (see Supplementary Figure 1) during that year. Despite these limitations, we used the most reliable data for Chile and state-of-the-art methodologies to gauge mortality dynamics across Chile.

Additionally, our results are limited in that stratified population counts are typically model-based estimates (except at census years), and might be biased. We studied the effect of alternative population estimates in final outcome measures, as described in the Supplement

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(Figures 3-15). Finally, because of our observational study design, we are only able to measure associations but not proper causal effects of poverty in mortality.

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Author contributions: GM, data curation, software, validation GM and JMA formal analysis, investigation,conceptualisation, methodology, project administration, resources, validation, visualisation, writing (original draft), and writing (review & editing) JMA funding acquisition, supervision.

Ethics approval: This research project does not require ethics approval as it uses only macro data that are freely available online.

Conflict of interest: None declared.

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Figure legends:

Figure 1

Life expectancy at birth by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 2

Probabiltiy of not surviving to 65 years by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 3

Time evolution (2002 to 2020 period) of the heterogeneity in life expectancy at birth (left), between 20 and 65 years (center) and at 65 years (right). **A** histograms of life expectancies over time, for male/female and urban/non-urban divisions. **B** Time evolution of Gini of the corresponding histograms in **A. C** Relative yearly changes in the Gini's with respect to previous years. Bars represent 95% credible intervals in B and C.

Figure 4

Changes in inequality of mortality in 2020 with respect to recent history were stronger in younger age groups. A Comparison between 2015-2019 and 2020 of the average years lived between 20 and 65, for

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males and females, as a function of poverty. B same as in A, but with life expectancy at 65.

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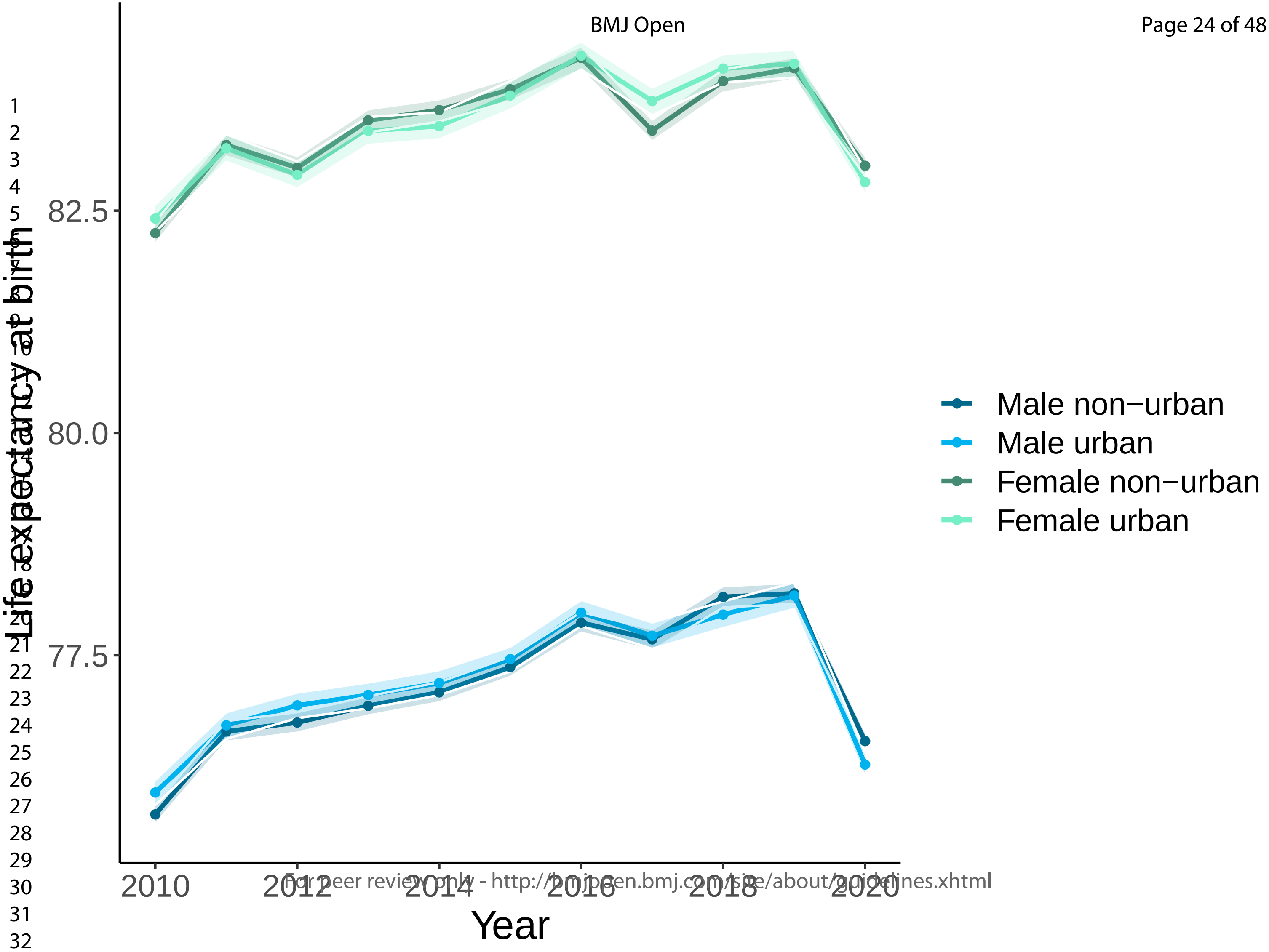
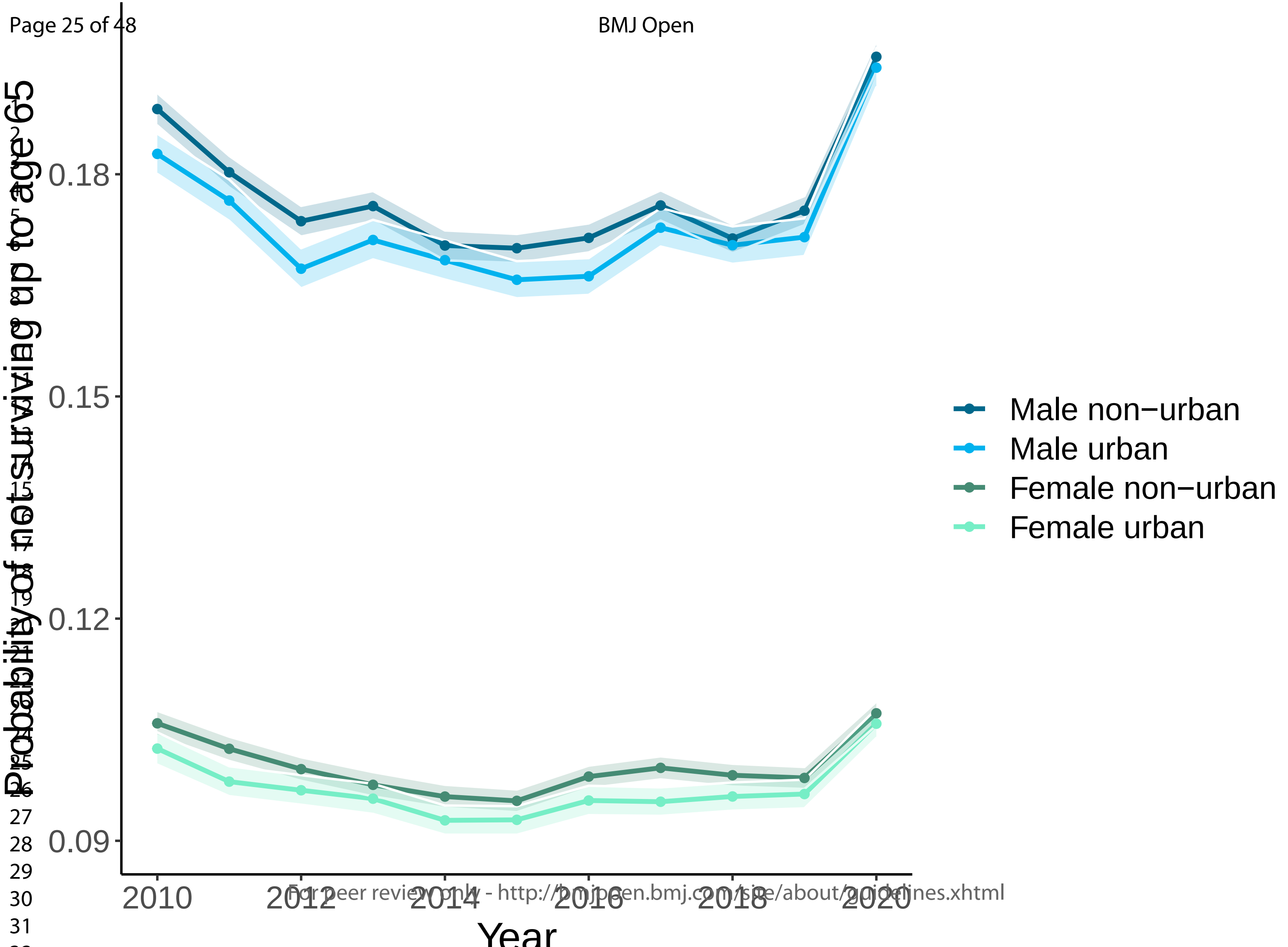
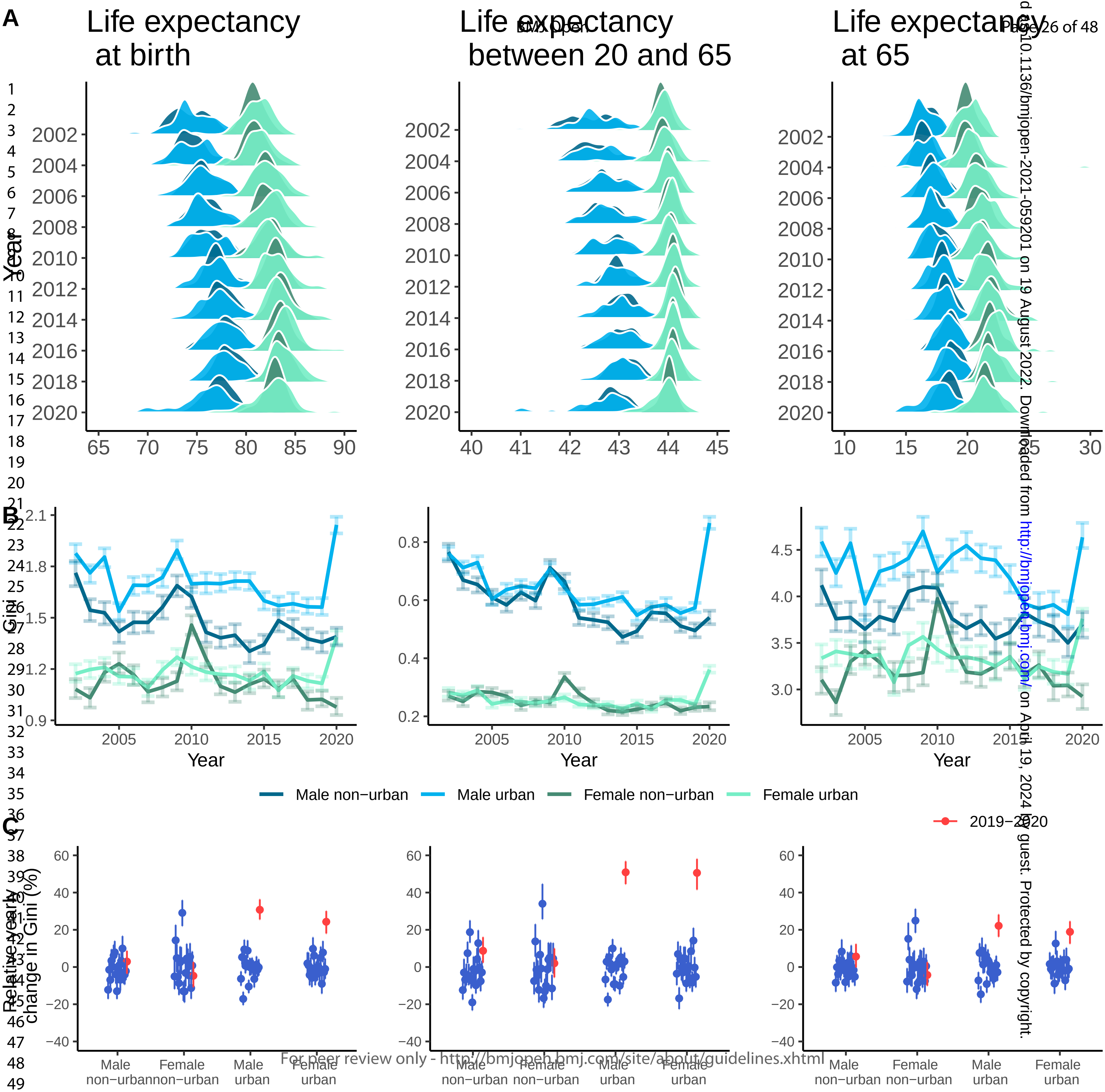

Life expectancy at birth
82.5
80.0
77.5
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban


Probability of not surviving up to age 65
0.18
0.15
0.12
0.09
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban



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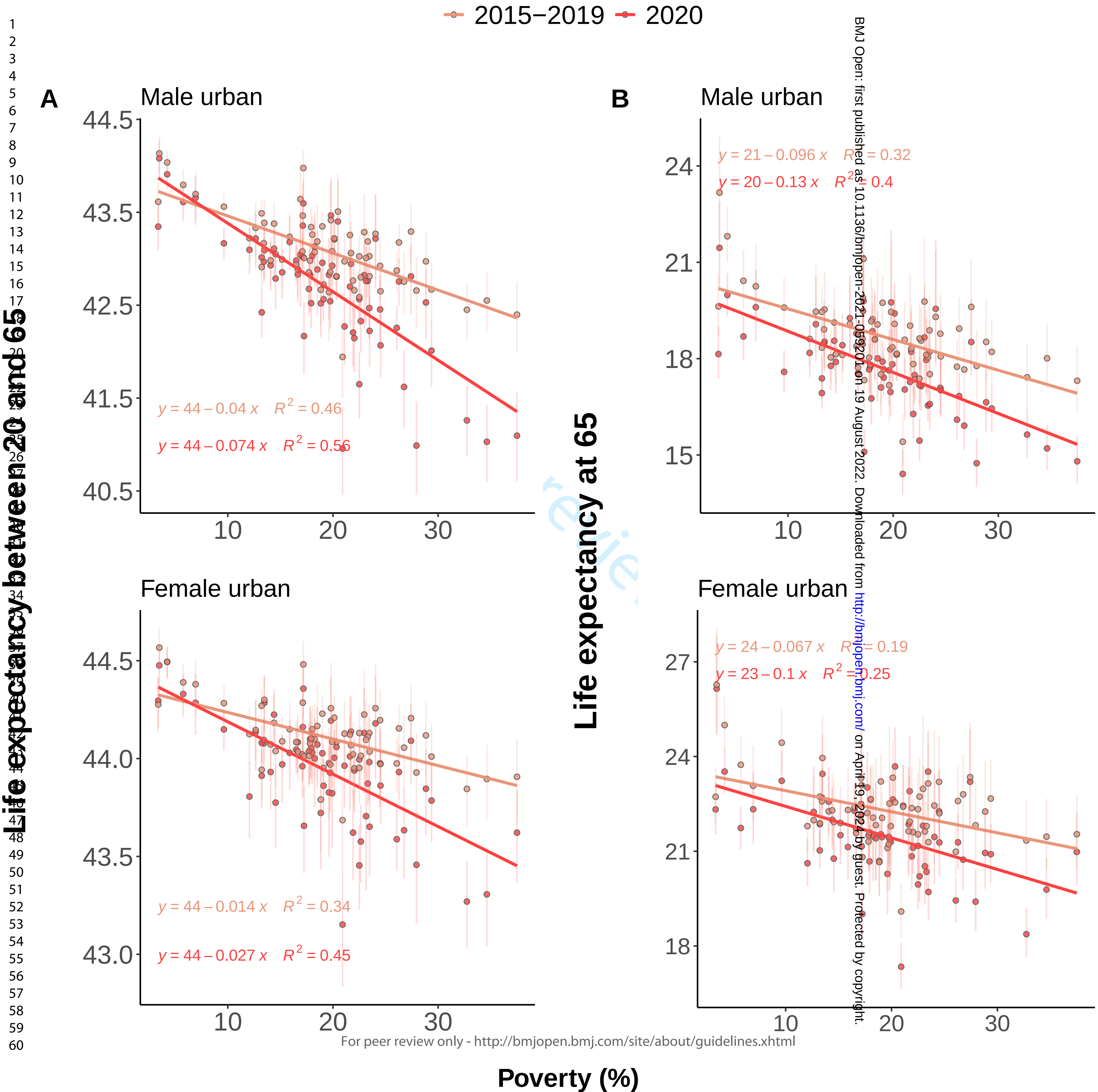

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The unequal impact of the COVID-19 pandemic on life expectancy across Chile: Supplementary materials

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1 Municipality classification

Chile is composed by a total of 16 regions. Each region is divided into smaller units, called municipalities. There are a total of 366 municipalities. We classified them as urban or non-urban based on the same criterion as in (*1*), that is, if the following two conditions hold: i) population density greater than 70 people per square kilometer, and ii) the proportion of people living in a urban environment is greater than 88%. We excluded all municipalities having fewer than 16,000 people according to census. In Tables 1 and 2 we show the total number of municipalities and people on urban, non-urban and excluded municipalities. The names of all municipalities and their urbanity status is shown in Table 3. We note that although 147 out of 339 municipalities where excluded, this only signifies a 7% of the population.

To study whether excluding small municipalities would bias our results, we created a super-municipality made by all the excluded. Notably, only two (out of 147) municipalities in this group would have been otherwise categorized as urban (El Quisco, Algarrobo), so it is safe to assume that this super-municipality is a non-urban one. In Fig. 2 we compare time evolution of life expectancy at birth and probability of dying before reaching age 65 (Figures 1 and 2 of the main text) for the non-urban municipalities, along with the values for the excluded (mostly non-urban) super-municipality. These are in close agreement.

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2 Estimation of mortality rates

We implemented method of (*2*), which consists on a hierarchical Bayesian model for the estimation of age-specific mortality rates on small area setups. The main idea is that by modeling a joint structure for these rates as a function of time and space, it would be possible to smooth out the effect of poor empirical estimates for years/locations where only a few population counts were available. In practice, we found that estimates were reasonable as long as the population of municipalities was reasonably large. We applied the algorithm to all municipalities for each region, and each year between 2002 and 2020, separating by gender (male, female, all). This gave a total of 16×3 algorithm runs. For each a run, we obtained a total of 3,000 Monte Carlo samples that we used for computing credible intervals. Additionally, we ran the algorithm to compute mortality rates for each region, and for the totality of urban and non-urban municipalities, as necessary. In all cases, we estimated mortality rates based on 5 years intervals, up to age 80+ (see below for a discussion of the cutoff age).

We excluded from our analyses some municipalities/years based on the visual inspection of total deaths per year. A cluster of 6 municipalities appeared to have corrupted data in the years surrounding 2004. Those are shown in Fig. 1.

3 Regressions

4 Sensitivity analyses

Since deaths are revealed to us in full detail, and because Chilean death recording system is reliable (*3*), the main source of corruption in mortality rates should stem from possible biases in population estimates. We explored what was the impact of different ways using population estimates in constructing the life tables, and used a number of several alternative estimates to re-create the results shown in the main text. These are explained below.

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Improving official projections

For year specific population counts between 2002 and 2020, we used the official population projections provided by the national institute of statistics, available at the municipality level and with resolution of years. These are made with simple interpolation and extrapolation methods as described in (*4*). However, we found that these projections were often inconsistent, mostly from 2017 on. Therefore, we considered two alternative estimates in addition to official projections, that only differed from official estimates starting 2017. For one estimate we used the official census counts at 2017 for years 2018, 2019 and 2020. The second estimate corresponds to the cohort component projection method, where we used births in 2017 (the only available) and deaths in 2018, 2019, 2020 to infer municipality and age specific population counts after 2017. In Fig. 5 we show comparisons between resulting estimates. We observe that indeed they produce different estimates, and differences between methods increase for later years. Notably, estimates based on official projections deviate wildly from other in some municipalities, indicating a possible lack of accuracy. In particular, we should expect that estimations based on projections at census year 2017 should be similar to the ones provided by our alternative estimates.

Maximum age

Another source of bias is given by cutoff age used when turning age-specific mortality rates into life expectancy estimates. Official census information (2002,2017) contains age-specific population counts for each municipality and gender, up to age 90. However, official census projections collapses all ages above 80 into one group. In Fig. 5A we compare results with the 80 and 90 cutoff, using official census data (only years 2002 and 2017), We observe that the 90 cutoff leads to consistently slightly higher life expectancies, with a difference that appears higher for older ages. Importantly, in 5B,C we also include other estimates, for reference. We observe large discrepancies in year 2017 when comparing official census and official projections. Once

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more, this is an indication that official projections are not accurate, as they become inconsistent in 2017 (i.e., official projections in year 2017 are far from official census in the same year).

Main results with alternative estimates In the main text we have used the cohort survival projection method. Here, we present results using the other two alternative methods. Figs. 5 and 6 correspond to Exhibits 1 and 2 in the main text, respectively. Figs. 7 and 8 complement Exhibit 3, and likewise, Figs. 9 and 10 complement Exhibit 4.

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5 Additional results

Fig.11 supplements Exhibit 4 by showing the relation between life expectancy and poverty in non-urban municipalities. No clear consistent pattern is observed. Also, in Fig. 12 we show the corresponding decreases of life expectancy over time as a function of poverty, in urban and non-urban setups. This figure is complemented by Fig. 13, which shows an even stronger correlation when using crowdedness as covariate, and Figs. 14 and 15, which show sensitivity of Fig. 12 to changes in the projection methodology.

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		Urban	Rural	Excluded	Total
Region	Tarapaca	2	0	5	7
	Antofagasta	0	3	6	9
	Atacama	0	3	6	9
	Coquimbo	2	6	7	15
	Valparaíso	9	15	14	38
	O'Higgins	2	14	17	33
	Maule	2	15	13	30
	Biobio	9	12	12	33
	La Araucanía	1	16	14	31
	Los Lagos	2	9	19	30
	Aysen	0	2	6	8
	Magallanes	0	2	6	8
	Metropolitana	36	13	3	52
	Los Ríos	1	7	4	12
	Arica y Parinacota	0	1	3	4
	Nuble	2	6	12	20
	Chile	68	124	147	339

Table 1: Number of municipalities for each strata (urban, rural) in our design, for each region.

References

1. J. Berdegué, E. Jara, F. Modrego, X. Sanclemente, A. Schejtman, *Rimisp, Santiago* (2009).

2. M. Alexander, E. Zagheni, M. Barbieri, *Demography* **54**, 2025 (2017).

3. G. E. Mena, *et al.*, *Science* **372** (2021).

4. I. N. de Estadísticas, Estimaciones y proyecciones de la población de chile 2002-2035 a nivel comunal. documento metodológico (2019 [Online].).

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Region	Urban	Rural	Excluded	Total
Tarapaca	299843	0	30715	330558
Antofagasta	0	552790	54744	607534
Atacama	448784	251371	57431	757586
Coquimbo	880647	787549	139030	1807226
Valparaíso	0	223516	62652	286168
O'Higgins	275211	477699	161645	914555
Maule	369493	559301	116156	1044950
Biobio	946952	504405	105448	1556805
La Araucanía	282415	522213	140985	945613
Los Lagos	407362	262009	159337	828708
Aysen	0	81777	20233	102010
Magallanes	0	153069	12304	165373
Metropolitana	6273435	809613	29760	7112808
Los Ríos	166080	181799	36958	384837
Arica y Parinacota	0	221364	4704	226068
Nuble	215646	152749	100611	469006
Chile	10565868	5741224	1232713	17539805

Table 2: Total populations for each region for each strata (urban, rural) in our design.

Region	Municipalities
Tarapaca	Iquique, Alto Hospicio, Pozo Almonte, Camina, Colchane, Huara, Pica
Antofagasta	Antofagasta, Calama, Tocopilla, Mejillones, Sierra Gorda, Taltal, Ollague, San Pedro de Atacama, Maria Elena
Atacama	Copiapo, Caldera, Vallenar, Tierra Amarilla, Chanaral, Diego de Almagro, Alto del Carmen, Freirina, Huasco
Coquimbo	La Serena, Coquimbo, Vicuna, Illapel, Los Vilos, Salamanca, Ovalle, Monte Patria, Andacollo, La Higuera, Paiguano, Canela, Combarbala, Punitaqui, Rio Hurtado.
Valparaíso	Valparaiso, Concon, Calera, La Cruz, San Antonio, Cartagena, San Felipe, Quilpue, Villa Alemana, Casablanca, Puchuncavi, Quintero, Vina del Mar, Los Andes, San Esteban, La Ligua, Cabildo, Quillota, Hijuelas, Nogales, Llaillay, Putaendo, Limache, Olmue, Juan Fernandez, Isla de Pascua, Calle Larga, Rinconada, Papudo, Petorca, Zapallar, Algarrobo, El Quisco, El Tabo, Santo Domingo, Catemu, Panquehue, Santa Maria
O'Higgins	Rancagua, Graneros, Coltauco, Donihue, Las Cabras, Machali, Mostazal, Pichidegua, Rengo, Requinoa, San Vicente, Pichilemu, San Fernando, Chimbarongo, Nancagua, Santa Cruz, Codegua, Coinco, Malloa, Olivar, Peumo, Quinta de Tilcoco, La Estrella, Litueche, Marchihue, Navidad, Paredones, Chepica, Lolol, Palmilla, Peralillo, Placilla, Pumanque
Maule	Talca, Curico, Constitucion, Maule, San Clemente, Cauquenes, Molina, Sagrada Familia, Teno, Linares, Colbun, Longavi, Parral, Retiro, San Javier, Villa Alegre, Yerbas Buenas Curepto, Empedrado, Pelarco, Pencahue, Rio Claro, San Rafael, Chanco, Pelluhue, Hualane, Licanten, Rauco, Romeral, Vichuquen
Biobio	Concepcion, Coronel, Chiguayante, Lota, Penco, San Pedro de la Paz, Talcahuano, Tome, Hualpen, Hualqui, Lebu, Arauco, Canete, Curanilahue, Los Alamos, Los Angeles, Cabrero, Laja, Mulchen, Nacimiento, Yumbel Florida, Santa Juana, Contulmo, Tirua, Antuco, Negrete, Quilaco, Quilleco, San Rosendo, Santa Barbara, Tucapel, Alto Biobio
La Araucanía	Temuco, Carahue, Cunco, Freire, Lautaro, Loncoche, Nueva Imperial, Padre Las Casas, Pitrufquen, Pucon, Vilcun, Villarrica, Angol, Collipulli, Curacautin, Traiguen, Victoria, Curarrehue, Galvarino, Gorbea, Melipeuco, Perquenco, Saavedra, Teodoro Schmidt, Tolten, Ercilla, Lonquimay, Los Sauces, Lumaco, Puren, Renaico
Los Lagos	Puerto Montt, Osorno, Calbuco, Frutillar, Los Muermos, Llanquihue, Puerto Varas, Castro, Ancud, Quellon, Purranque, Cochamo, Fresia, Maullin, Chonchi, Curaco de Velez, Dalcahue, Puqueldon, Queilen, Quemchi, Quinchao, Puerto Octay, Puyehue, Rio Negro, San Juan de la Costa, San Pablo, Chaiten, Futaleufu, Hualaihue, Palena
Aysen	Coyhaique, Aysén Lago Verde, Cisnes, Guaitecas, Cochrane, Chile Chico, Rio Ibanez
Magallanes	Punta Arenas, Natales Laguna Blanca, San Gregorio, Cabo de Hornos, Porvenir, Primavera, To
Metropolitana	Santiago,Cerrillos, Cerro Navia, Conchali, El Bosque, Estacion Central, Huechuraba, Independencia, La Cisterna, La Florida, La Granja, La Pintana, La Reina, Las Condes, Lo Barnechea, Lo Espejo, Lo Prado, Macul, Maipu, Nunoa, Pedro Aguirre Cerda, Penalolen, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado,Penaflor, Pirque, San Jose de Maipo, Colina, Lampa, Tiltil, Buin, Calera de Tango, Paine, Melipilla, Curacavi, Talagante, El Monte, Isla de Maipo, Alhue, Maria Pinto, San Pedro
Los Ríos	Valdivia, Lanco, Los Lagos, Mariquina, Paillaco, Panguipulli, La Union, Rio Bueno, Corral, Mafil, Futrono, Lago Ranco
Arica y Parinacota	Arica Camarones, Putre, General Lagos
Nuble	Chillan, Chillan Viejo, Bulnes, Quillon, San Ignacio, Yungay, San Carlos, Coihueco, El Carmen, Pemuco, Pinto, Quirihue, Cobquecura, . Coelemu, Ninhue, Portezuelo, Ranquil, Treguaco, Niquen, San Fabian

Table 3: Names of all urban (red), rural (blue) and excluded (black) municipalities of each region.

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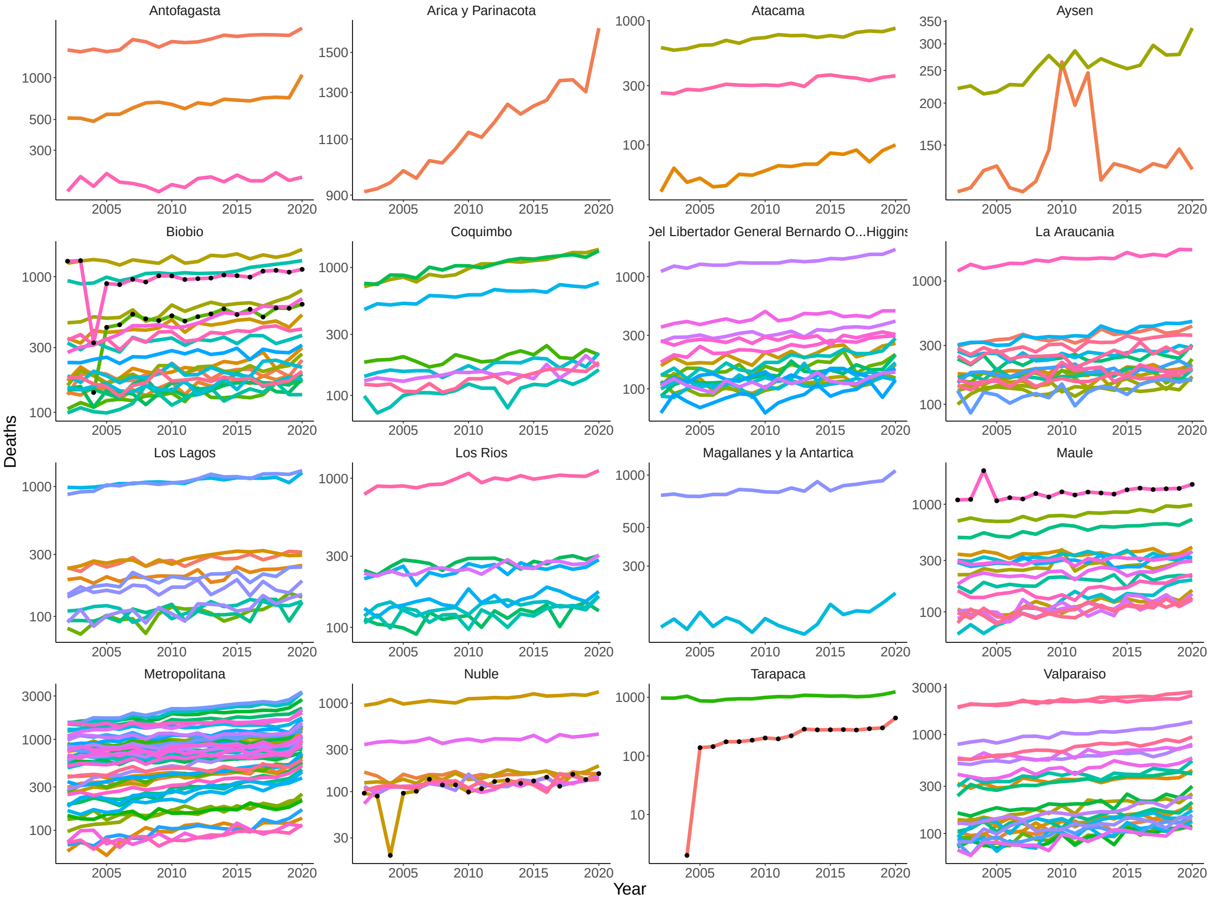

Figure 1: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring years (Talcahuano, Hualpén, Diego de Almagro, Talca, Alto Hospicio, Chillán Viejo).

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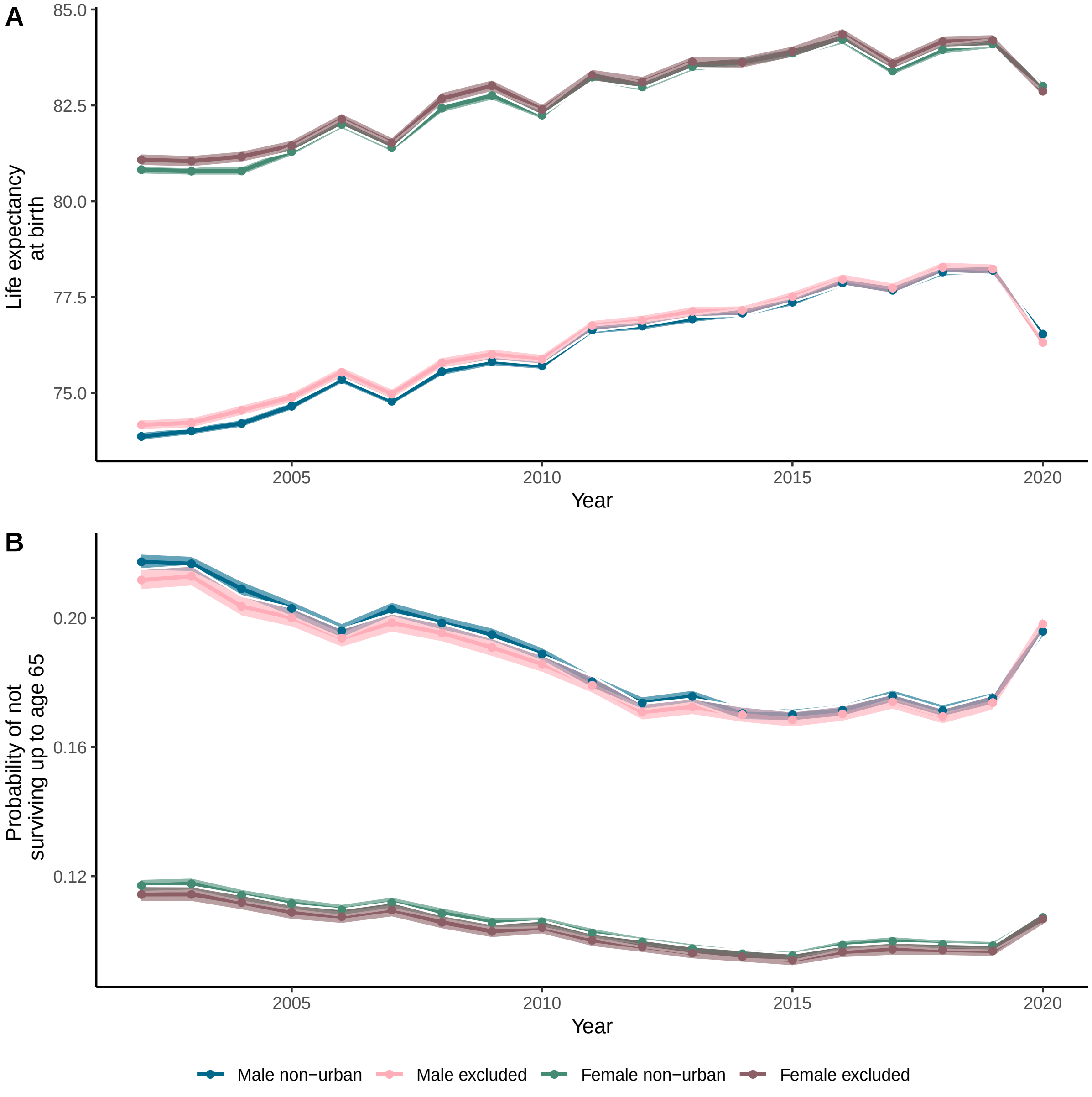

Figure 2: **A**. Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B**. Same as **A**, but with likelihood of dying before reaching 65.

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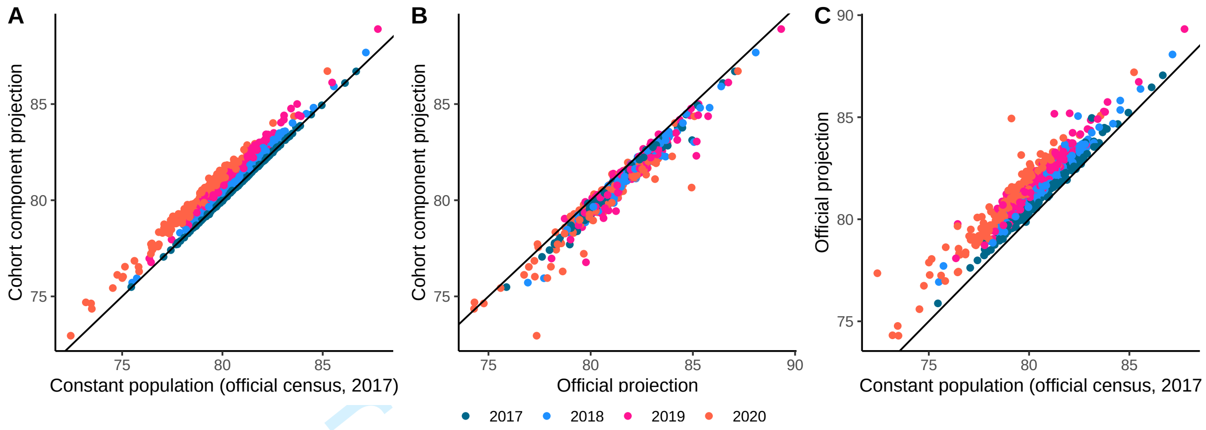

Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival projection. In **C** we compare official projection with the one that has constant population.

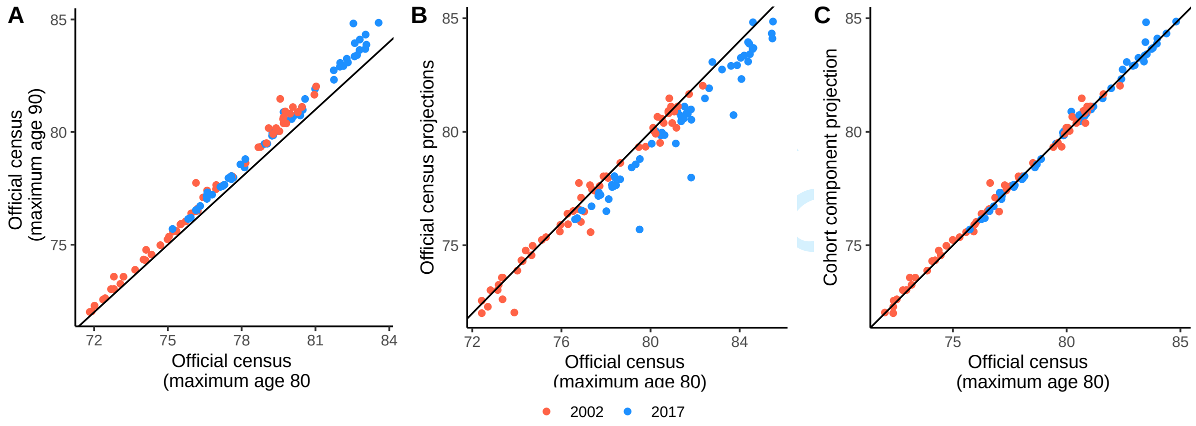

Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with official projections in that year. We note that discrepancies become more significant in year 2017, indicating the need for an alternative methodology. In **C** we compare official census (80 as cutoff age) with our cohort survival projection method. They are in close agreement, as they are both based on official census data, and not projections.

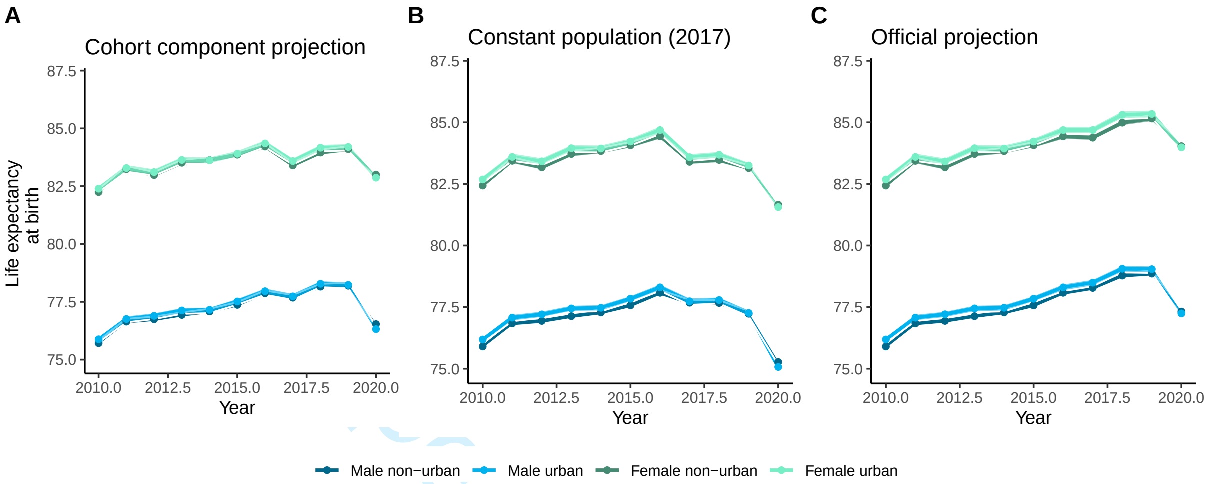

Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with **A**.

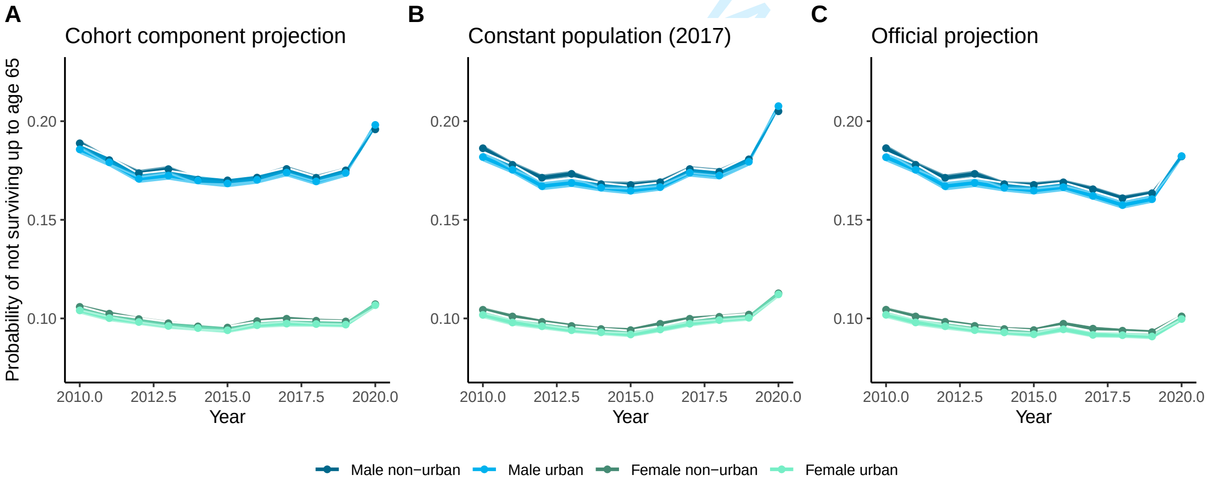

Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with **A**.

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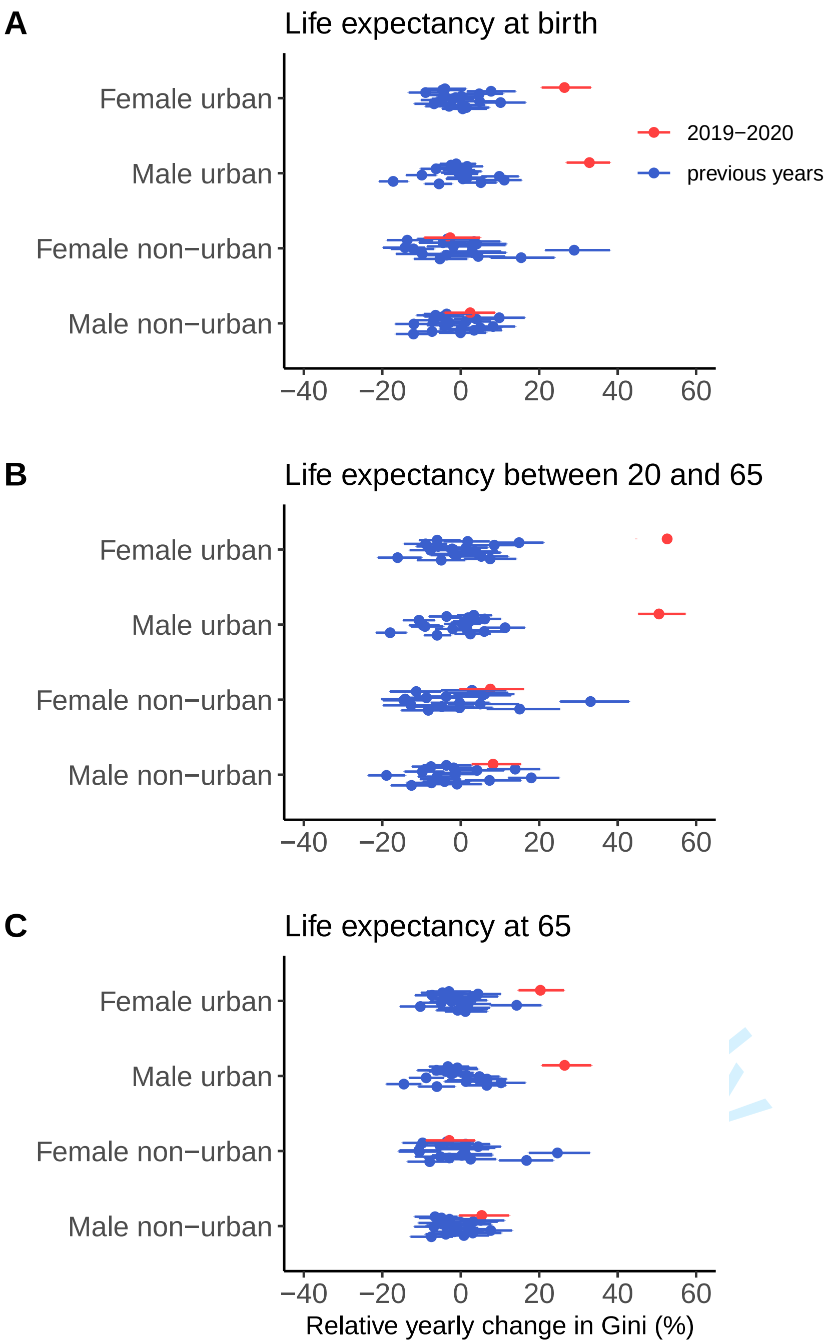

Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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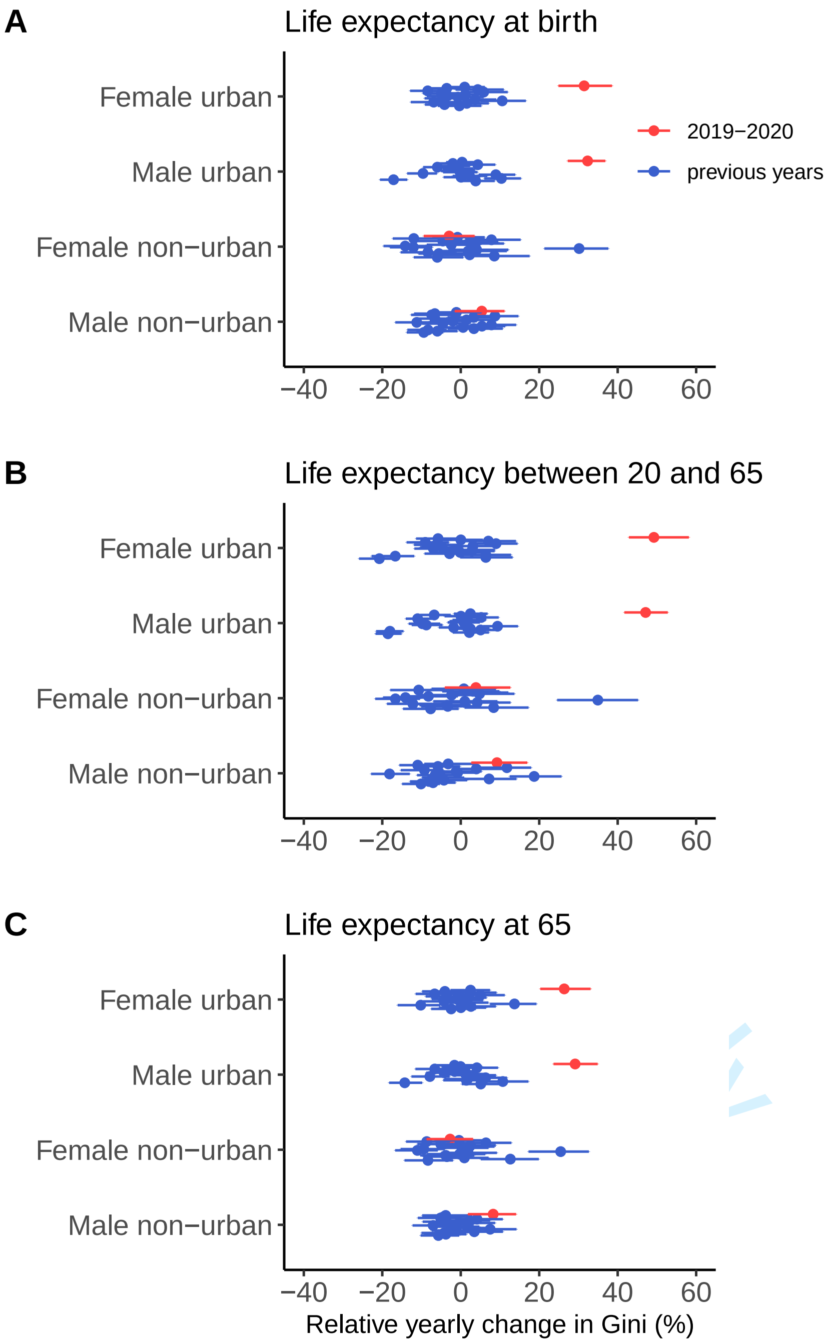

Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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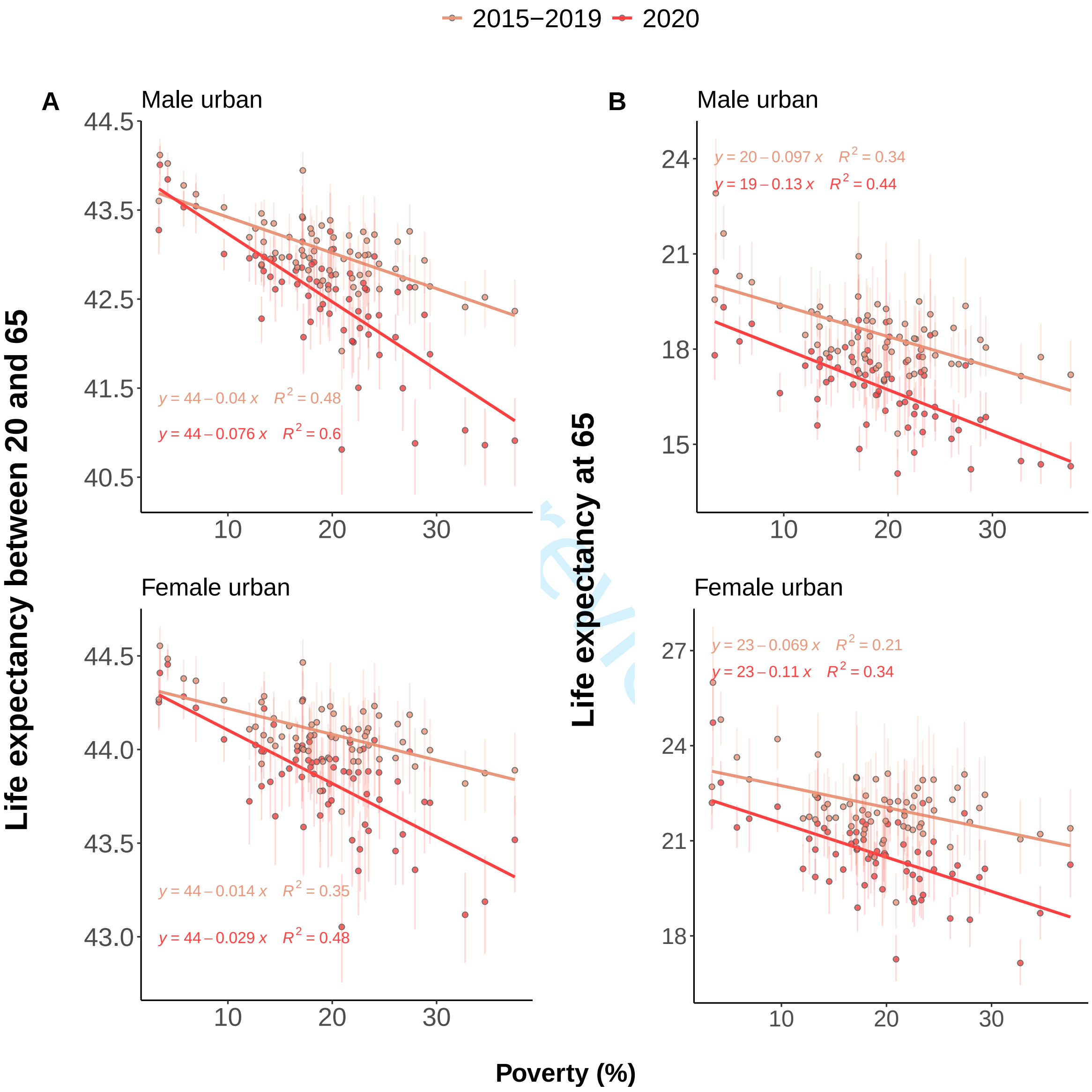

Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019 and 2020, and may be compared with Exhibit 4 in the main text.

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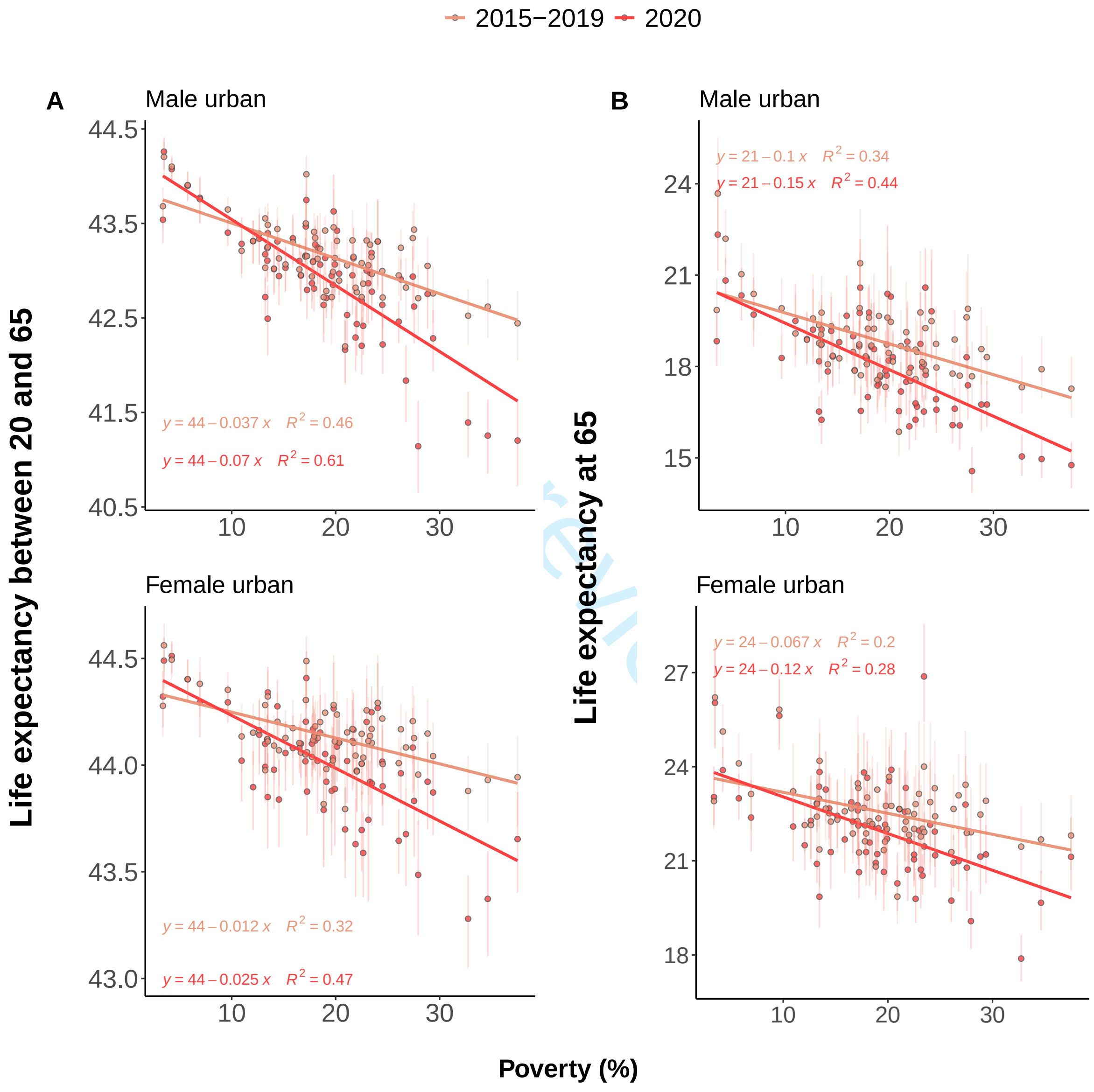

Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

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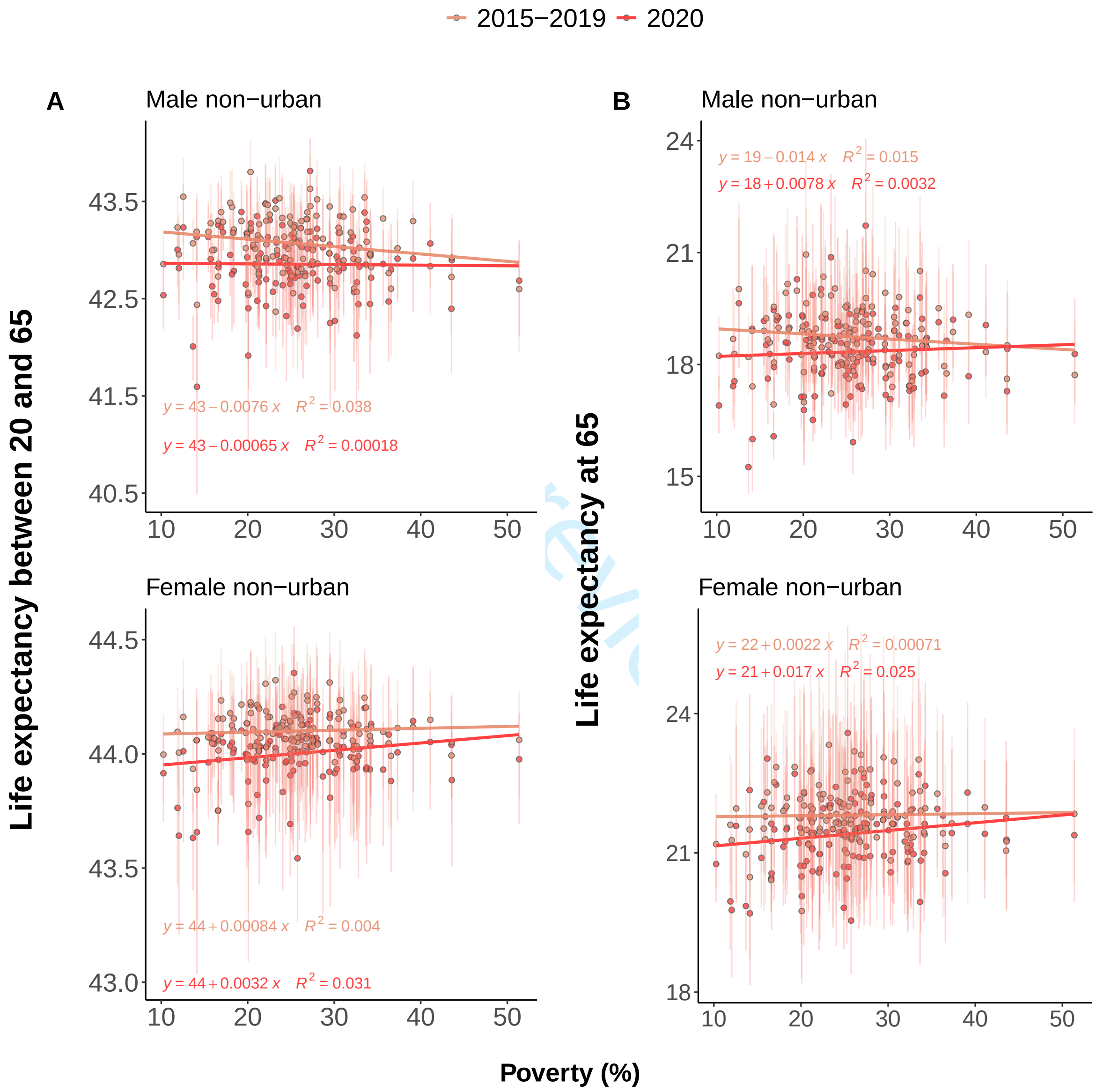

Figure 11: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

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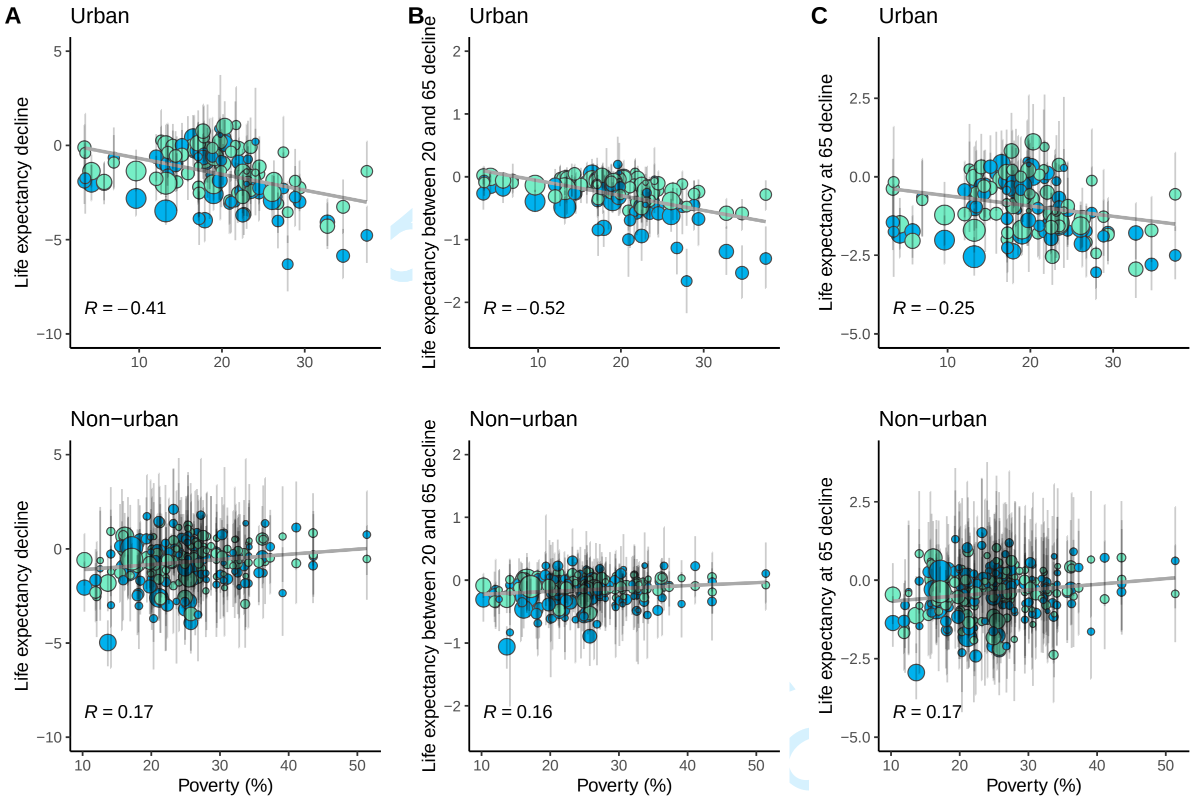

Figure 12: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and second row, respectively. A strong effect appears in urban setups, and the correlation is stronger in for life expectancy between 20 and 65.

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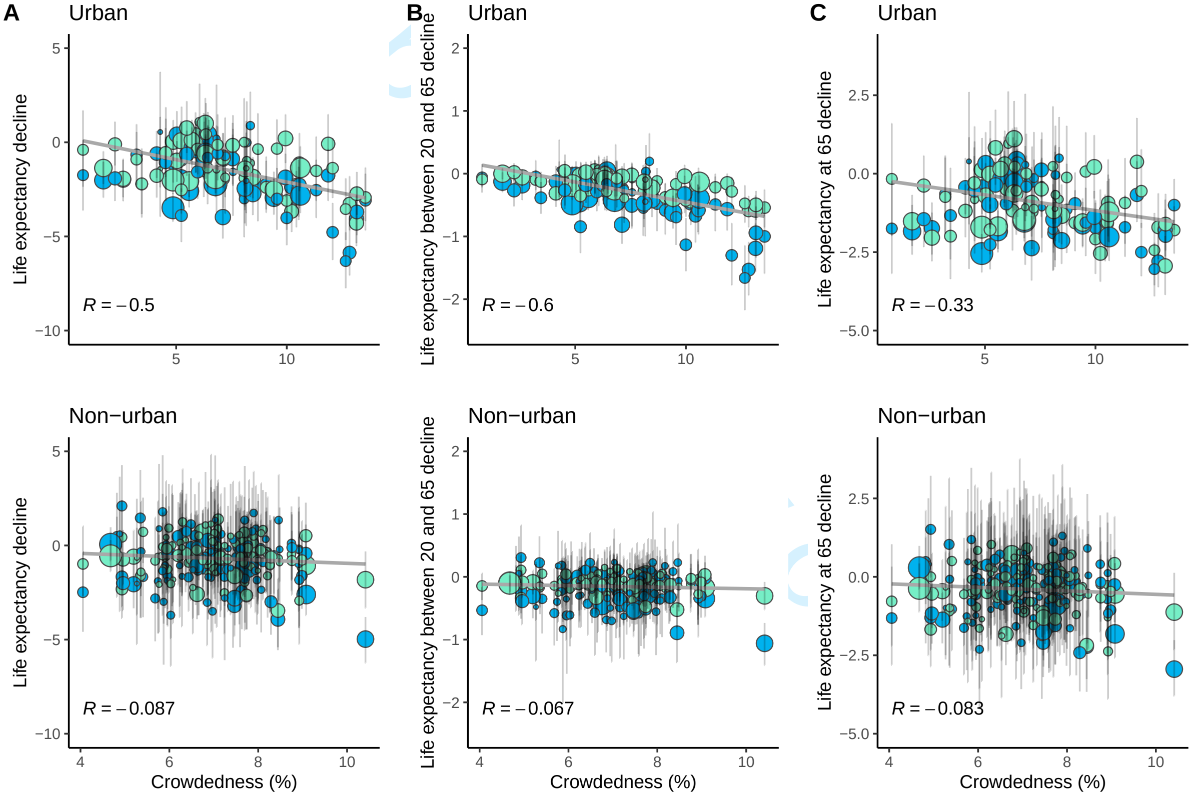
Figure 13: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in a crowded home. Each dot is a municipality, separated by gender(colors) Urban and non-urban municipalities are shown in first and second row, respectively.



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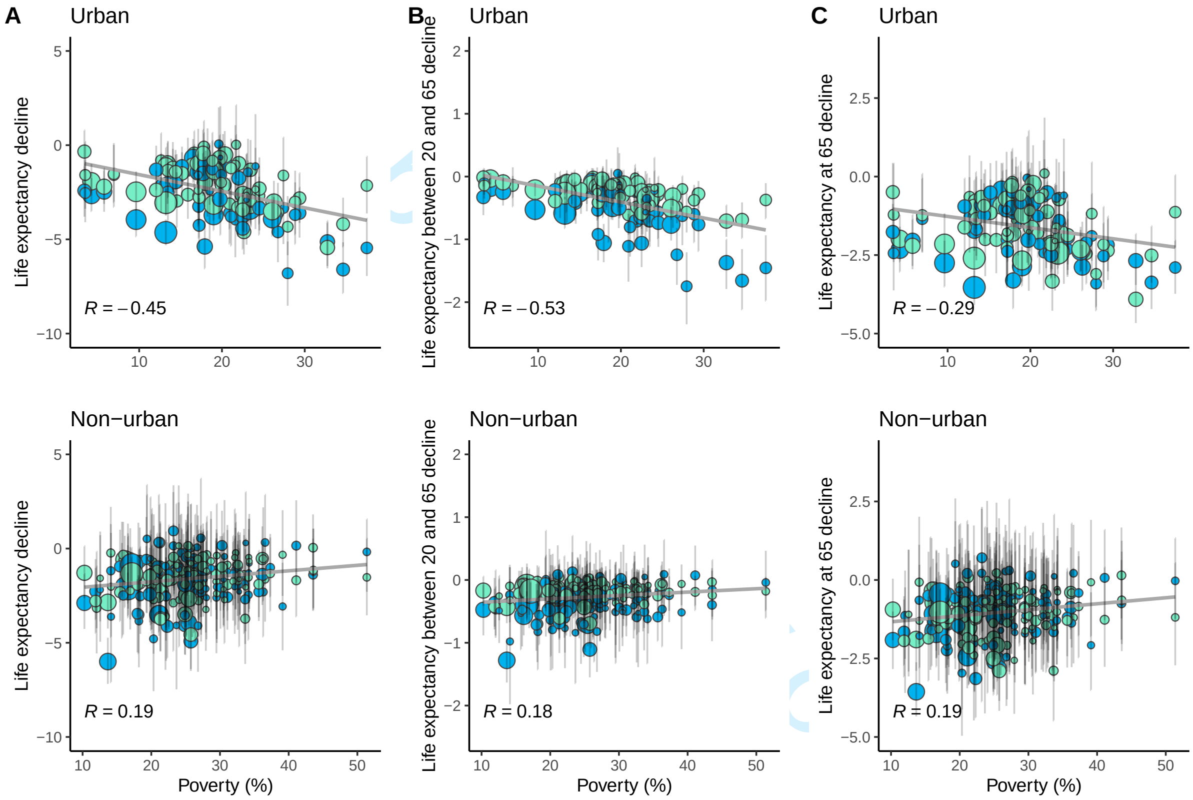

Figure 14: Same as 12 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

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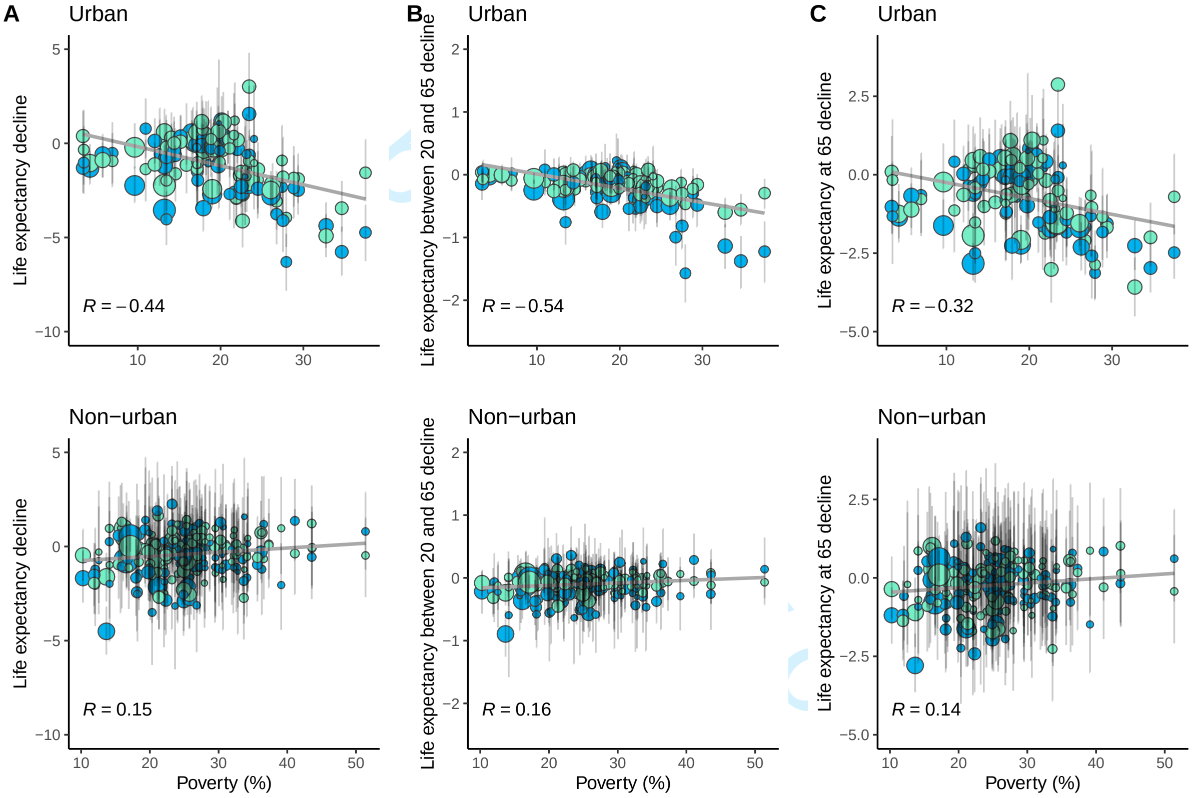

Figure 15: Same as 12 but with population estimates given by official projections.

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	**Recommendation**	**Page No**
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*8*
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	7-9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	7-9
		(*c*) Explain how missing data were addressed	7-8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	7-8
		(*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	NA
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	NA
Outcome data	15*	Report numbers of outcome events or summary measures	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-8
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-11
Discussion			
Key results	18	Summarise key results with reference to study objectives	9-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-11
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The unequal impact of the COVID-19 pandemic in 2020 on life expectancy across urban areas in Chile: A cross-sectional demographic study.

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Title: The unequal impact of the COVID-19 pandemic in 2020 on life expectancy across urban areas in Chile: A cross-sectional demographic study.

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Word count (main text, references): 3229

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Abstract (227 words):

Objectives: To quantify the impact of the COVID-19 pandemic on life expectancy in Chile categorized by rural and urban areas, and to correlate life expectancy changes with socioeconomic factors at the municipal level.

Design: Retrospective cross-sectional demographic analysis using aggregated national all-cause death data stratified by year, sex and municipality during the period 2010-2020.

Setting and population: Chilean population by age, sex and municipality from 2002 to 2020.

Main Outcome measures: Stratified mortality rates using a Bayesian methodology. These were based on Vital and demographic statistics from the national institute of statistics and department of vital statistics of ministry of health. With this, we assessed the unequal impact of the pandemic in 2020 on life expectancy across Chilean municipalities for males and females and analyzed previous mortality trends since 2010.

Results: Life expectancy declined for both males and females in 2020 compared to 2019. Urban areas were the most affected, with males losing 1.89 years and females 1.33 years. The strength of the decline in life expectancy correlated positively with indicators of social deprivation and poverty. Also, inequality in life expectancy between municipalities increased, largely due to excess mortality among the working-age population in socially disadvantaged municipalities.

Conclusions: Not only do people in poorer areas live shorter lives, they also have been substantially more affected by the COVID-19 pandemic, leading to increased population health inequalities. Quantifying the impact of the COVID-19 pandemic on life expectancy provides a more comprehensive picture of the toll.

Keywords: COVID-19, Latin America, Mortality, Health Inequalities

Strengths and limitations

- We study mortality and life-expectancy patterns in Chile at the subnational level.
- Hierarchical Bayesian modeling was used to estimate reliable mortality levels and life expectancy.
- The study is limited by the small number of death counts in some areas, which increases uncertainty around estimates.
- Data quality may be a limitation for the study, which we try to overcome with the Bayesian estimation of mortality.

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Main Text

Introduction

Most Latin American countries experienced substantial progress in reducing premature mortality while increasing health standards over the last century and into the first fifteen years of the twenty-first century.[1,2] But this progress has been reversed, as Latin American countries have been severely affected by the COVID-19 pandemic.[3] The region became the hotspot of the pandemic in June 2020 and by March 2022 more than one and a half million COVID-19 deaths have been reported.[4]

After decades of sustained improvements in life expectancy, leading to levels comparable to low mortality countries, Chile experienced losses in this indicator in 2020 due to increased excess mortality during the COVID-19 pandemic (11 months for females and 1.3 years among males).[5] While national figures are important and informative, they conceal heterogeneity at the subnational level, which can be substantial. Evidence from Latin American countries suggests that the COVID-19 pandemic has disproportionately affected disadvantaged groups with low socioeconomic status with large regional variation.[6-10] In the context of Santiago, Chile's capital, the observed worse outcomes in more deprived areas were explained by the combination of lower access to healthcare, poorer baseline health status of individuals, higher exposure to Sars-COV2 because of a reduced compliance with shelter-in-place orders (in turn, reflecting the inability to work from home), and by an ineffective epidemic surveillance system whose resources were predominantly allocated to more affluent areas, hampering early containment efforts.[6]

One key question is how the interplay of social and demographic factors at a more granular geographic scale affected life expectancy during the first year of the pandemic. Focusing on differences in mortality by age, sex, social deprivation and urbanity, we aimed at exploring two main hypotheses. First, life expectancy has been affected differently for females and males by urbanity status. Since COVID-19 first waves concentrated their impact on urban centers in Chile,[6] we expect that declines of life expectancy were larger in urban areas. Also, since COVID-19 outcomes are typically worse among males at the national level,[11,12] we expect larger drops in life expectancy among males in urban areas. Second, larger life-expectancy losses were more predominant in socially deprived areas. This hypothesis stems from the known negative correlation between poverty and life expectancy.[13] But because of the intricate relation between COVID-19 deaths by age and social deprivation, it is not straightforward to determine whether this correlation became

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stronger during the pandemic. In support of this hypothesis, recent research in Chile's Capital showed a strong negative correlation between excess deaths and socioeconomic status. This correlation was particularly stark among younger age-groups but eventually evened out for the elderly.[6] Since younger ages affect more life expectancy, it is likely that excess young-age mortality may have increased inequality in life expectancy. Alternatively, since death rates increased exponentially with age and losses in life expectancy in low mortality countries have been attributed mostly to mortality above age 60,[5] it is likely that the pandemic in 2020 was such a strong shock that excess mortality differentials decreased, leading to reducing inequalities between municipalities.

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This article contributes towards a more comprehensive understanding of the COVID-19 pandemic's burden on population health by estimating life expectancy across Chilean municipalities by sex using a powerful Bayesian methodology.[14] We contextualize our results with past trends of progress and disparities in life expectancy, and comment on the the relevance of acknowledging such persisting disparities in the design of social security mechanisms. Our study is a step towards explaining the varied impacts of the pandemic by analyzing trends in life expectancy over age at a more granular level and by correlating life expectancy losses with indicators of poverty in Chile.

Study Data and Methods

Data

We used data on births and deaths by age, sex and municipality from publicly available vital statistics.[15] These data were complemented with official population counts by age (single years of age from 0 to 89 and collapsed in 90+), sex and municipality from the 2002 and 2017 censuses available from the National Institute of Statistics (INE).[16] We also used official population projections between 2002 and 2020 centered at the 2017 census.[17] Unlike censuses, these projections collapsed all ages greater than 80 in one single group. We only observed minor changes in our estimates based on whether the open ended interval started at 80 or 90, but we did observe that life expectancy estimates based on 2017 projections were substantially higher than the ones based on the 2017 census. We explain this by a possible inadequacy of the official projection for later years. Because of this reason, we considered two alternative population estimates for 2017 onwards. The first one assumes that population counts remain fixed for years 2018,2019 and 2020. In the second one, we projected forward the population using the cohort component method[18] with 2017 as baseline assuming zero migration. We also used census data to classify municipalities as urban or non-urban,[19] if the following two conditions held: i) population density greater than 70 people per square kilometer, and ii) the proportion of people living in an urban environment is greater than 88%. Chile is made up of 366 municipalities and according to this criteria, 35% are classified as urban, making up for 65% of the population (17,539,805, as per the 2017 Census). See Supplementary Tables 1-3 for details. Data on poverty and crowdedness were taken from the CASEN survey by the Chilean Ministry of Social Development and Family.[20] CASEN is the most comprehensive official poverty survey available in Chile. For poverty, we used the 'multidimensional poverty' indicator. In CASEN, a household is defined to suffer from multidimensional poverty if it accumulates 22.5% of deprivation according to a weighted score that takes into account 15 variables including income, access to healthcare, labor, social security, housing and social cohesion among others. Likewise, a household is considered crowded if there are 2.5 or more people per room. All data used in our analyses have been compiled and made publicly available[21].

Mortality estimation

We performed mortality analyses at the municipality level since this is the finest spatial unit at which age and sex specific demographic data and covariates (poverty, crowdedness) are available. By considering municipalities as units we are able to investigate the variation of the resulting distribution of mortality and its relation with other covariates (e.g. age, urbanity status, poverty). Age specific death rates for each municipality by sex were estimated implementing a recently developed methodology[14] based on a hierarchical Bayesian model[22] using population and death counts. There are two main advantages to this Bayesian methodology: first, the fact that municipality specific rates are assumed to be samples from a population with global parameters enables the sharing of information between municipalities, helping to smooth out the noisy estimates that would otherwise be obtained if we relied only on empirical counts. This is important because of the increased likelihood of low death counts on each strata in small municipalities. Second, by appealing to the Bayesian methodology we immediately obtain credible intervals for each of our estimates.{Updating}

Life tables

Life tables were calculated using the age specific death rates estimated in the Bayesian procedure following standard techniques.[18] From these, period life expectancy at birth, temporary life expectancy between ages 20 and 65, and remaining life expectancy at age 65 were obtained. Life expectancy at birth refers to the average years a cohort of newborns is expected to live given the current mortality conditions. Similarly, life expectancy at age 65 refers to the average years individuals aged 65 are expected to live if they were to experience the current mortality conditions throughout their lives. Given the emerging evidence about how younger age groups below age 65 have also been affected by the pandemic in the context of Chile, we constructed a measure to capture average longevity over working ages through temporary life expectancy. Temporary life expectancy between ages 20 and 65 refers to the average years lived between these ages given prevalent mortality conditions.[23] For example, if no one were to die between these ages, then the temporary life expectancy would be the full 45 years. To complement our analysis we also consider the probability of dying before age 65 as an indicator of premature mortality.

Measuring heterogeneity

We leverage the availability of life expectancy estimates at the municipality level to conceive a fictitious population where each municipality is a sample. We quantify the heterogeneity of this population through the Gini coefficient.[24] The Gini coefficient is a standard indicator of inequality employed in social sciences. In the context of this paper, the Gini coefficient expresses the degree of inequality in life expectancy across municipalities. With our methodology, we can seamlessly quantify temporal changes of the Gini for different strata (male/female, urban/non-urban) and report credible intervals.

Patient and Public Involvement

No patients were involved in this paper, all the analyses are based on aggregated data.

Results

Trends in life expectancy at birth and survivorship below age 65.

Males and females from both urban and non-urban areas experienced steady increases in life expectancy at birth from 2010 to 2019. Females showed higher life expectancy at birth than males in all groups. In contrast, higher mortality during 2020 led to sharp decreases in life expectancy at birth (Figure 1) compared to 2019. Life expectancy among males in urban and non-urban areas declined by 1.89 (95% CI: 1.68,2.09) and 1.66 (1.50,1.80) years, respectively. Among females, life expectancy losses were 1.33 (1.11,1.55) and 1.10 (0.92,1.28) years, respectively. The magnitude of the decline from

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2019 to 2020 offset most gains in life expectancy experienced in the last decade, especially in urban areas. In fact, 68% of the municipalities analyzed ended up with lower life expectancy than in 2015, and this number rose to 75% in urban municipalities. In terms of individuals, 76% (non-urban) and 78% (urban) of the population lived in a municipality that faced a decline in life expectancy compared to 2015.

Declines in the probability of surviving to age 65 (Figure 2) between 2019 and 2020 indicate that changes in life expectancy cannot be fully attributed to increased mortality in older age groups only. While mortality above age 65 has been documented as one of the main contributors to declines in life expectancy internationally, substantial increases in mortality below age 65 are apparent in our results, especially among males in urban areas.

Changes in disparities in life expectancy during the COVID-19 pandemic in 2020

Figure 3 shows the time evolution of the inequality in life expectancies across municipalities, and shows the striking impact of COVID-19 on this quantity. Inequality increased in urban areas from 2019 to 2020, with changes oscillating around 25%, a rate not seen in the recent past. The magnitude of increase is much larger in male and female life expectancy between ages 20 and 65 from urban areas (50.9% and 50.6% for males and females respectively). Contrarily, in non-urban areas we do not observe changes deviating significantly from usual year-to-year fluctuations. Altogether, these results indicate not only that mortality during 2020 became more unequal, but that this inequality was driven mostly by the younger age group.

Histograms in Figure 3 suggest that the abrupt increase in inequality during 2020 can be attributed to heavier left tails of the life expectancy distribution, indicating an increase in the amount of municipalities with a much lower-than-average life expectancy. To better understand the factors driving this spike in inequality, we investigated how declines in life expectancy during 2020 correlated with social deprivation indicators including poverty and crowdedness focusing only on mortality above age 20 across urban areas. Figure 4 shows the negative association between poverty and life expectancy between age 20 ang 65, and life expectancy at age 65. To underscore how the relationship changed in the course of 2020, we stratified the results juxtaposing the previous five years (2015-19) with 2019-20. Results show a strong historical negative correlation between life expectancies in both age groups, sexes and poverty levels. Males in the top poverty decile have a 4.39-years lower life expectancy than in the bottom decile. They also live on average 0.92 less years between 20 and 65, and 2.22 from 65 onwards.

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For females, these numbers are 2.51, 0.31 and 1.55 years. During 2020, the slope decreased, suggesting that those municipalities with higher levels of poverty experienced greater losses in life expectancy. This dependency was stronger in the younger age group.

In contrast, while life expectancy at 65 declined during 2020, this decline was less unequal over the poverty gradient, consistent with the hypothesis that this group contributed less to inequality in changes in life expectancy. To formalize these observations, we performed regression analyses to model the interactions between year and poverty level through varying intercepts and slopes. We only found significant changes in the slope for average years lived between 20 and 65. For males, this translated into an additional difference of 0.78 years between the highest and lowest poverty deciles (p=0). For females, this difference was 0.30 (p<0.001).

Discussion

Urban areas that are exposed to higher poverty or social disadvantages experienced larger losses in life expectancy during the COVID-19 crisis in 2020 in Chile. Our results reveal that losses were unevenly shared across municipalities, over age, and by sex, leading to increasing inequality in life expectancy across regions in Chile. Moreover, consistent with previous research on increased mortality at younger ages in 2020 in deprived municipalities in Chile’s capital,[6] our research shows that working age mortality was one of the main drivers of increasing inequality in life expectancy across Chile.

Analysis of life expectancy in 2020 compared with the previous five years (2015-19) show that poorer urban municipalities suffered a double burden. Not only did they show lower levels of life expectancy but they also experienced greater losses in life expectancy. This is consistent with previous research documenting larger mortality increases for the lower educated groups in Chile’s capital.[25] Furthermore, when we disaggregate by age groups, we observe that the association between life expectancy for working age individuals (between ages 20 and 65) and levels of poverty became stronger compared to previous years. This is consistent with previous evidence had documented a positive association between income and life expectancy at retirement.[26] This suggests that even if the burden of mortality during the COVID-19 crisis has been concentrated at older ages,[27] contributing substantially to life expectancy declines during 2020,[28] inequalities in life expectancy were largely driven by increased mortality in working ages at higher levels of poverty. A potential explanation is that the working age population’s availability to work from home and be less exposed to heightened risk of COVID-19 and its consequences varies across poverty levels. Deprived populations in Chile's capital experienced higher fatality rates as a consequence of worse baseline individual health status and to an overwhelmed healthcare system.[6] Similarly, evidence from the US suggests that those individuals with less availability to work from home had higher death rates compared to those that could afford working from home in 2020.[29]

An open question is whether this sudden increase in inequality amounts to a shock that will be followed by a recovery to pre-pandemic levels, or whether these changes will persist in the long term. Beyond the immediate increase in premature mortality, this is relevant because failing to acknowledge inequalities in mortality may compromise the progressiveness and actuarial fairness of social security and public pension systems in the long term,[30,31] which could be translated into higher mortality in the future. Similarly, the scars left by the pandemic, including a weak health system, may increase mortality from multiple causes of death. For example, postponed cancer treatments and failure to detect other chronic degenerative diseases timely may lead to lower levels of life expectancy in the long term than it was projected. This highlights the need for accurate and timely data on other causes of death. Future analysis should focus on analyzing the consequences of the COVID-19 pandemic, including multiple causes of death and diseases to study the direct impacts from COVID-19 mortality as well as the indirect impacts through other pathways of diseases and conditions.[32] Our research, in this sense, provides a first outlook by focusing on all-cause mortality.

As shown by our results, the case of Chile underscores the dire widening of an already large mortality gap between those living in deprived conditions and those living with higher income during the COVID-19 crisis. Evidence shows that the health consequences of external shocks such a pandemic or an economic crisis are not spread equally across social deprivation levels.[33] The COVID-19 pandemic reminds us of the ever-present risk of such events, whose cumulative impact may partially explain the ever-existing gaps in mortality. Therefore, the way that this crisis has exposed the vulnerabilities of socially deprived populations is a call to challenge the monolithic view of a country's demographics in the design of social security systems. New strategies incorporating a public health perspective that considers widening inequalities should be implemented to minimize the impacts of the COVID-19 pandemic on the health status of the Chilean population both immediately and in the long term.

Limitations

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This study had several limitations. First, while Chile's vital registration is one of the most reliable in Latin America, there are likely to be inaccuracies in mortality registration due to age misreporting and coverage across municipalities, as well as systematic age overstatement.[34] Delays in recording deaths may lead to incompleteness issues especially in urban areas. Our results on life expectancy declines and mortality inequalities may be considered a lower bound because of these issues. The effect of systematic age overstatement is likely to affect our results too. However, there is no information on what the age pattern of overstatement is during the pandemic. To mitigate these inaccuracies and their effects on life expectancy estimates, we used a hierarchical Bayesian model that helped to retrieve a reasonable mortality profile across regions. Another limitation is that because of the low number of deaths observed in some municipalities, the degree of uncertainty around the estimates was very high, not allowing us to include them in our analysis with confidence. We excluded municipalities by sex with less than 16,000 people (as per the 2017 census), as we observed that life expectancy estimates were unstable even with our adopted Bayesian methodology. However, we grouped them together and reproduced all results to avoid systematic exclusion. Results were consistent and are shown in Supplementary Figure 1. Almost all of these were non-urban municipalities. Some other six municipalities were excluded in 2004 based on a visual inspection of mortality trends that were clearly indicative of coding errors in the mortality database (see Supplementary Figure 2) during that year. Despite these limitations, we used the most reliable data for Chile and state-of-the-art methodologies to gauge mortality dynamics across Chile. Additionally, our results are limited in that stratified population counts are typically model-based estimates (except at census years), and might be biased. We studied the effect of alternative population estimates in final outcome measures, as described in the Supplement (Figures 3-15). Finally, because of our observational study design, we are only able to measure associations but not proper causal effects of poverty in mortality.

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Data availability statement: This analysis used publicly available data. All data are available at https://doi.org/10.5281/zenodo.6797737 and scripts generating results are available at http://www.github.com/gomena/life-expectancy-chile.

Author contributions: GM: data curation, software, validation; GM and JMA: formal analysis, investigation, conceptualisation, methodology, project administration, resources, validation, visualisation, writing (original draft), and writing (review & editing).

Ethics approval: This research project does not require ethics approval as it uses only macro data that are freely available online.

Conflict of interest: None declared.

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Figure legends:

Figure 1

Life expectancy at birth by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 2

Probabiltiy of not surviving to 65 years by sex and condition of Urban and Non-urban in Chile. Notes: Solid lines correspond to estimates based on the entire population on each group, with bands indicating 95% credible regions.

Figure 3

Time evolution (2002 to 2020 period) of the heterogeneity in life expectancy at birth (left), between 20 and 65 years (center) and at 65 years (right). **A** histograms of life expectancies over time, for male/female and urban/non-urban divisions. **B** Time evolution of Gini of the corresponding histograms in **A**. **C** Relative yearly changes in the Gini's with respect to previous years. Bars represent 95% credible intervals in B and C.

Figure 4

Changes in inequality of mortality in 2020 with respect to recent history were stronger in younger age groups. A Comparison between 2015-2019 and 2020 of the average years lived between 20 and 65, for males and females, as a function of poverty. B same as in A, but with life expectancy at 65.

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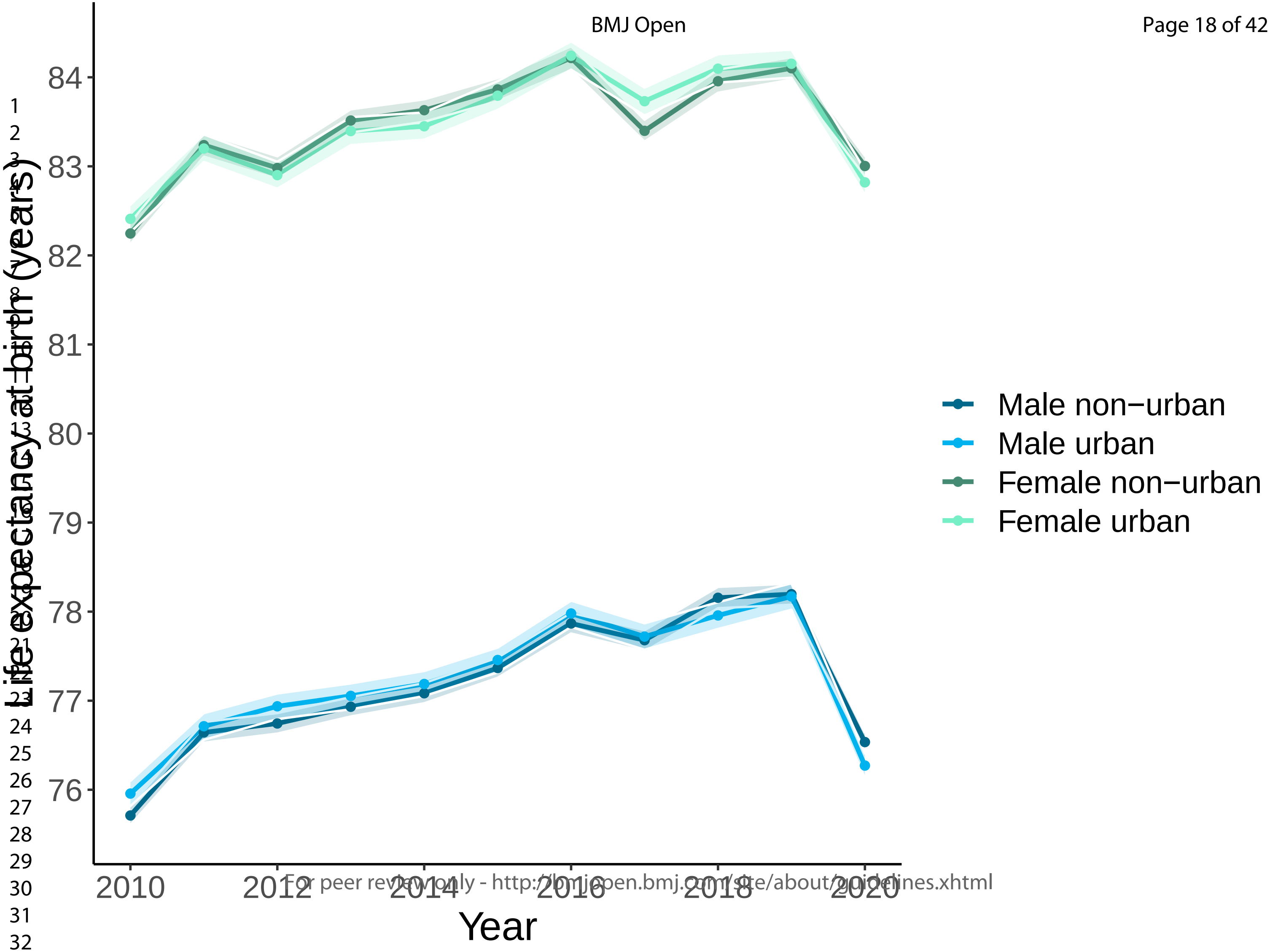
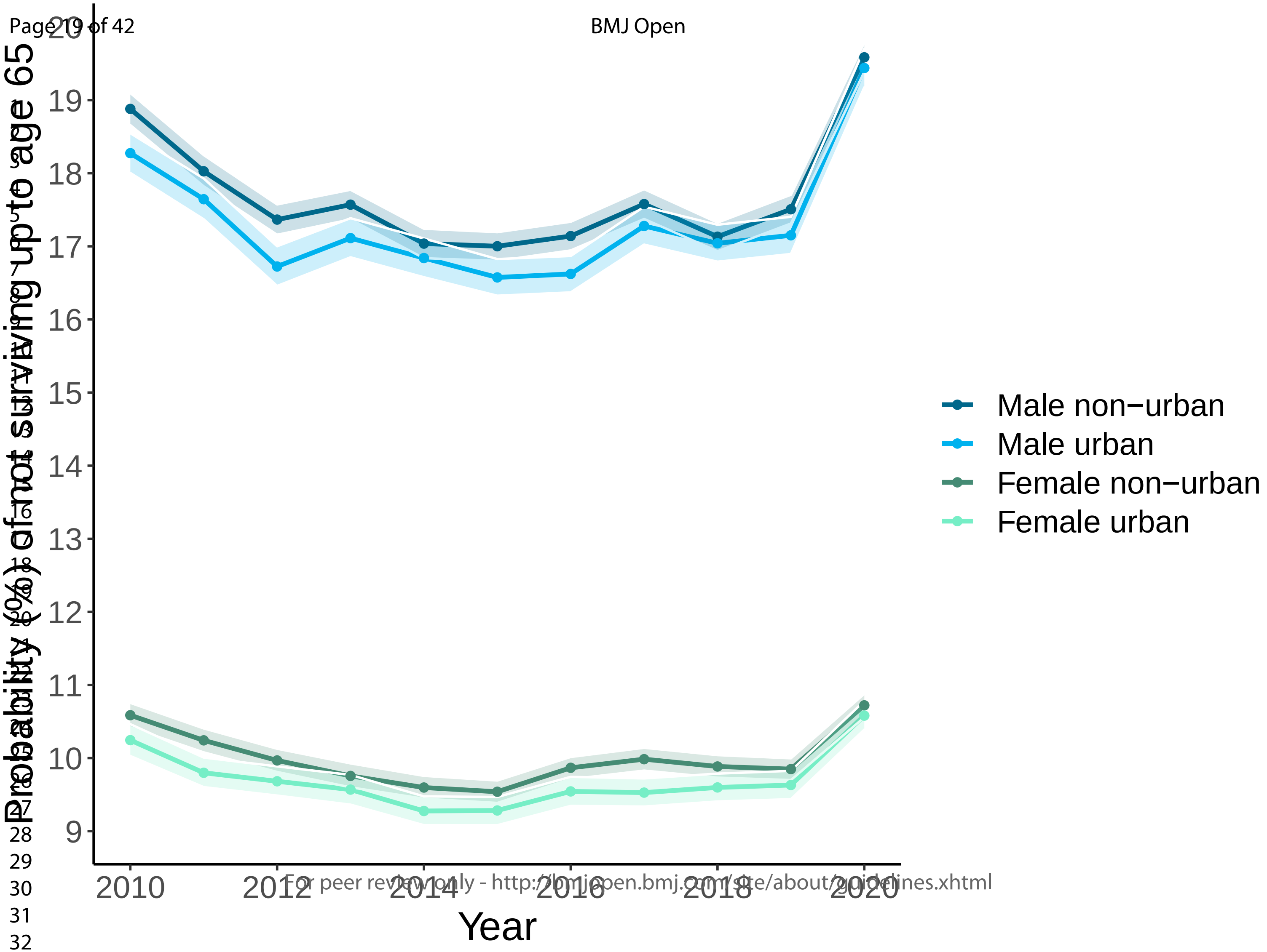
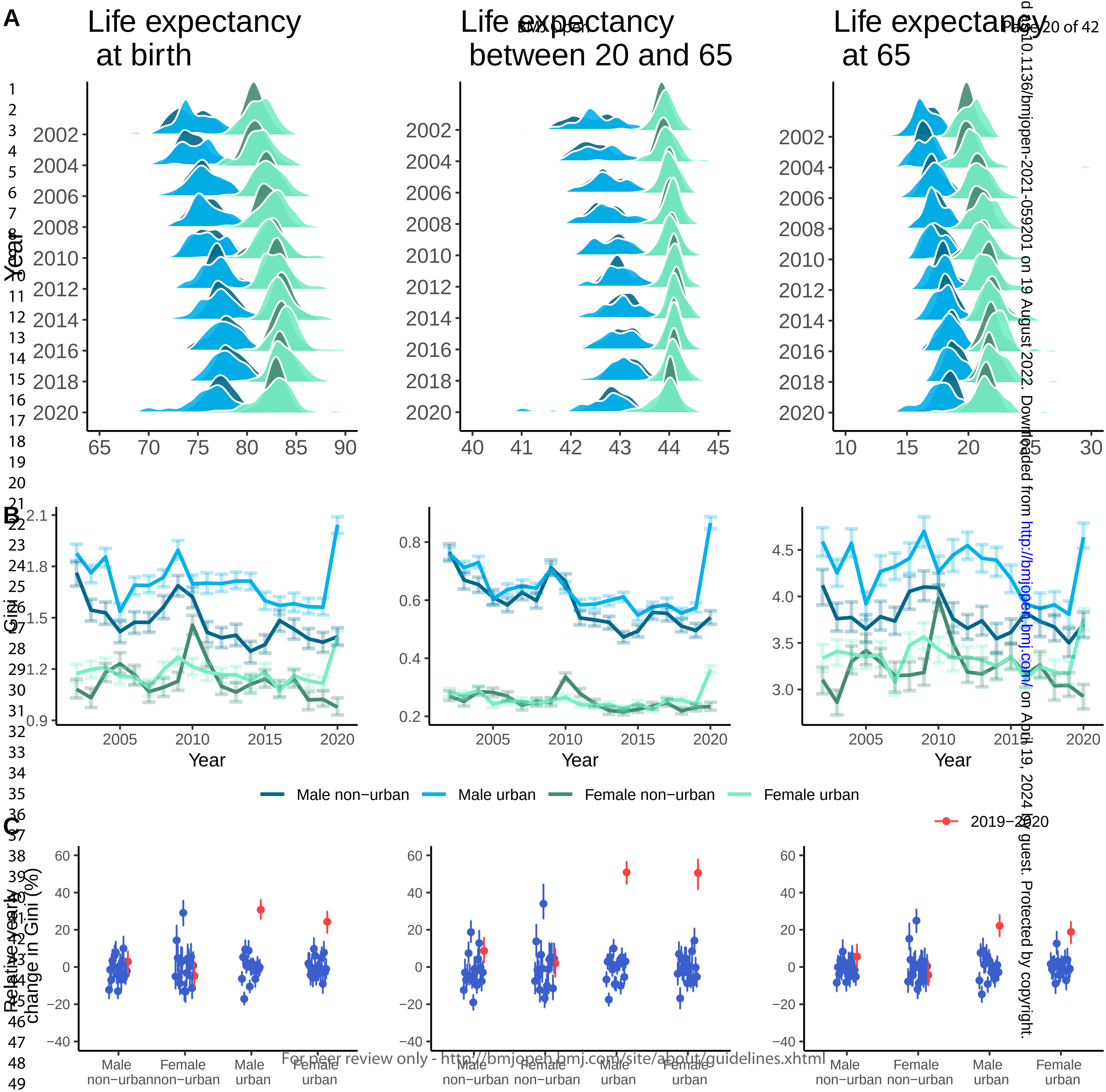

Life expectancy at birth (years)
84
83
82
81
80
79
78
77
76
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban


Probability (%) of not surviving up to age 65
20
19
18
17
16
15
14
13
12
11
10
9
2010
2012
2014
2016
2018
2020
Year
Male non−urban
Male urban
Female non−urban
Female urban



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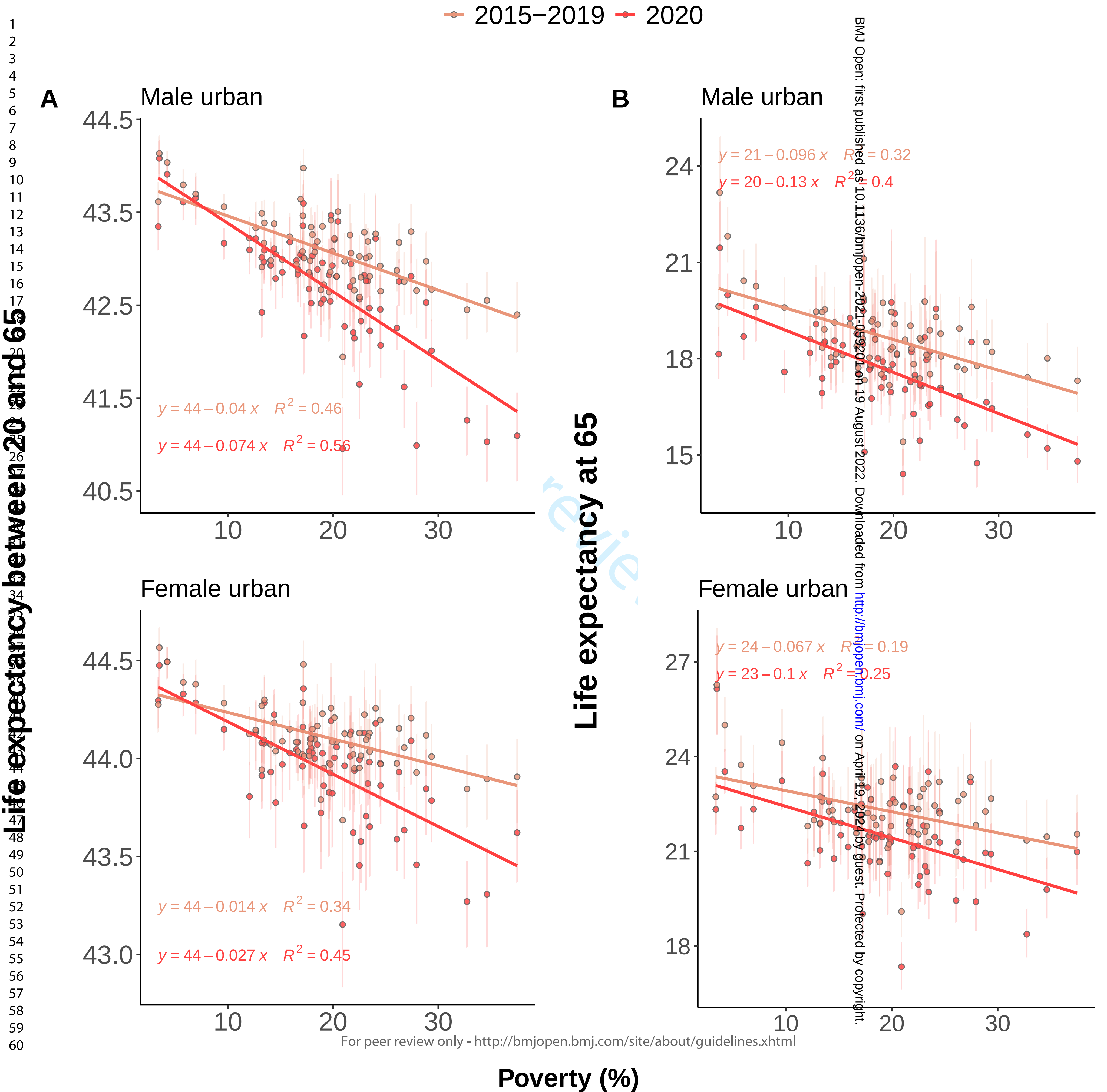

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The unequal impact of the COVID-19 pandemic on life expectancy across Chile: Supplementary materials

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1 Municipality classification

Chile is composed by a total of 16 regions. Each region is divided into smaller units, called municipalities. There are a total of 366 municipalities. We classified them as urban or non-urban based on the same criterion as in (*1*), that is, if the following two conditions hold: i) population density greater than 70 people per square kilometer, and ii) the proportion of people living in a urban environment is greater than 88%. We excluded all municipalities having fewer than 16,000 people according to census. In Tables 1 and 2 we show the total number of municipalities and people on urban, non-urban and excluded municipalities. The names of all municipalities and their urbanity status is shown in Table 3. We note that although 147 out of 339 municipalities where excluded, this only signifies a 7% of the population.

To study whether excluding small municipalities would bias our results, we created a super-municipality made by all the excluded. Notably, only two (out of 147) municipalities in this group would have been otherwise categorized as urban (El Quisco, Algarrobo), so it is safe to assume that this super-municipality is a non-urban one. In Fig. 1 we compare time evolution of life expectancy at birth and probability of dying before reaching age 65 (Figures 1 and 2 of the main text) for the non-urban municipalities, along with the values for the excluded (mostly non-urban) super-municipality. These are in close agreement.

2 Estimation of mortality rates

We implemented method of (*2*), which consists on a hierarchical Bayesian model for the estimation of age-specific mortality rates on small area setups. The main idea is that by modeling a joint structure for these rates as a function of time and space, it would be possible to smooth out the effect of poor empirical estimates for years/locations where only a few population counts were available. In practice, we found that estimates were reasonable as long as the population of municipalities was reasonably large. We applied the algorithm to all municipalities for each region, and each year between 2002 and 2020, separating by gender (male, female, all). This gave a total of 16×3 algorithm runs. For each a run, we obtained a total of 3,000 Monte Carlo samples that we used for computing credible intervals. Additionally, we ran the algorithm to compute mortality rates for each region, and for the totality of urban and non-urban municipalities, as necessary. In all cases, we estimated mortality rates based on 5 years intervals, up to age 80+ (see below for a discussion of the cutoff age).

We excluded from our analyses some municipalities/years based on the visual inspection of total deaths per year. A cluster of 6 municipalities appeared to have corrupted data in the years surrounding 2004. Those are shown in Fig. 2.

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3 Regressions

4 Sensitivity analyses

Since deaths are revealed to us in full detail, and because Chilean death recording system is reliable (*3*), the main source of corruption in mortality rates should stem from possible biases in population estimates. We explored what was the impact of different ways using population estimates in constructing the life tables, and used a number of several alternative estimates to re-create the results shown in the main text. These are explained below.

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Improving official projections

For year specific population counts between 2002 and 2020, we used the official population projections provided by the national institute of statistics, available at the municipality level and with resolution of years. These are made with simple interpolation and extrapolation methods as described in (*4*). However, we found that these projections were often inconsistent, mostly from 2017 on. Therefore, we considered two alternative estimates in addition to official projections, that only differed from official estimates starting 2017. For one estimate we used the official census counts at 2017 for years 2018, 2019 and 2020. The second estimate corresponds to the cohort component projection method, where we used births in 2017 (the only available) and deaths in 2018, 2019, 2020 to infer municipality and age specific population counts after 2017. In Fig. 5 we show comparisons between resulting estimates. We observe that indeed they produce different estimates, and differences between methods increase for later years. Notably, estimates based on official projections deviate wildly from other in some municipalities, indicating a possible lack of accuracy. In particular, we should expect that estimations based on projections at census year 2017 should be similar to the ones provided by our alternative estimates.

Maximum age

Another source of bias is given by cutoff age used when turning age-specific mortality rates into life expectancy estimates. Official census information (2002,2017) contains age-specific population counts for each municipality and gender, up to age 90. However, official census projections collapses all ages above 80 into one group. In Fig. 5A we compare results with the 80 and 90 cutoff, using official census data (only years 2002 and 2017), We observe that the 90 cutoff leads to consistently slightly higher life expectancies, with a difference that appears higher for older ages. Importantly, in 5B,C we also include other estimates, for reference. We observe large discrepancies in year 2017 when comparing official census and official projections. Once more, this is an indication that official projections are not accurate, as they become inconsistent in 2017 (i.e., official projections in year 2017 are far from official census in the same year).

Main results with alternative estimates In the main text we have used the cohort survival projection method. Here, we present results using the other two alternative methods. Figs. 5 and 6 correspond to Exhibits 1 and 2 in the main text, respectively. Figs. 7 and 8 complement Exhibit 3, and likewise, Figs. 9 and 10 complement Exhibit 4.

5 Additional results

Fig.11 supplements Exhibit 4 by showing the relation between life expectancy and poverty in non-urban municipalities. No clear consistent pattern is observed. Also, in Fig. 12 we show the corresponding decreases of life expectancy over time as a function of poverty, in urban and non-urban setups. This figure is complemented by Fig. 13, which shows an even stronger correlation when using crowdedness as covariate, and Figs. 14 and 15, which show sensitivity of Fig. 12 to changes in the projection methodology.

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		Urban	Rural	Excluded	Total
Region	Tarapaca	2	0	5	7
	Antofagasta	0	3	6	9
	Atacama	0	3	6	9
	Coquimbo	2	6	7	15
	Valparaíso	9	15	14	38
	O'Higgins	2	14	17	33
	Maule	2	15	13	30
	Biobio	9	12	12	33
	La Araucanía	1	16	14	31
	Los Lagos	2	9	19	30
	Aysen	0	2	6	8
	Magallanes	0	2	6	8
	Metropolitana	36	13	3	52
	Los Ríos	1	7	4	12
	Arica y Parinacota	0	1	3	4
	Nuble	2	6	12	20
	Chile	68	124	147	339

Table 1: Number of municipalities for each strata (urban, rural) in our design, for each region.

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Region	Urban	Rural	Excluded	Total
Tarapaca	299843	0	30715	330558
Antofagasta	0	552790	54744	607534
Atacama	448784	251371	57431	757586
Coquimbo	880647	787549	139030	1807226
Valparaíso	0	223516	62652	286168
O'Higgins	275211	477699	161645	914555
Maule	369493	559301	116156	1044950
Biobio	946952	504405	105448	1556805
La Araucanía	282415	522213	140985	945613
Los Lagos	407362	262009	159337	828708
Aysen	0	81777	20233	102010
Magallanes	0	153069	12304	165373
Metropolitana	6273435	809613	29760	7112808
Los Ríos	166080	181799	36958	384837
Arica y Parinacota	0	221364	4704	226068
Nuble	215646	152749	100611	469006
Chile	10565868	5741224	1232713	17539805

Table 2: Total populations for each region for each strata (urban, rural) in our design.

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Region	Municipalities
Tarapaca	Iquique, Alto Hospicio, Pozo Almonte, Camina, Colchane, Huara, Pica
Antofagasta	Antofagasta, Calama, Tocopilla, Mejillones, Sierra Gorda, Taltal, Ollague, San Pedro de Atacama, Maria Elena
Atacama	Copiapo, Caldera, Vallenar, Tierra Amarilla, Chanaral, Diego de Almagro, Alto del Carmen, Freirina, Huasco
Coquimbo	La Serena, Coquimbo, Vicuna, Illapel, Los Vilos, Salamanca, Ovalle, Monte Patria, Andacollo, La Higuera, Paiguano, Canela, Combarbala, Punitaqui, Rio Hurtado.
Valparaíso	Valparaiso, Concon, Calera, La Cruz, San Antonio, Cartagena, San Felipe, Quilpue, Villa Alemana, Casablanca, Puchuncavi, Quintero, Vina del Mar, Los Andes, San Esteban, La Ligua, Cabildo, Quillota, Hijuelas, Nogales, Llaillay, Putaendo, Limache, Olmue, Juan Fernandez, Isla de Pascua, Calle Larga, Rinconada, Papudo, Petorca, Zapallar, Algarrobo, El Quisco, El Tabo, Santo Domingo, Catemu, Panquehue, Santa Maria
O'Higgins	Rancagua, Graneros, Coltauco, Donihue, Las Cabras, Machali, Mostazal, Pichidegua, Rengo, Requinoa, San Vicente, Pichilemu, San Fernando, Chimbarongo, Nancagua, Santa Cruz, Codegua, Coinco, Malloa, Olivar, Peumo, Quinta de Tilcoco, La Estrella, Litueche, Marchihue, Navidad, Paredones, Chepica, Lolol, Palmilla, Peralillo, Placilla, Pumanque
Maule	Talca, Curico, Constitucion, Maule, San Clemente, Cauquenes, Molina, Sagrada Familia, Teno, Linares, Colbun, Longavi, Parral, Retiro, San Javier, Villa Alegre, Yerbas Buenas Curepto, Empedrado, Pelarco, Pencahue, Rio Claro, San Rafael, Chanco, Pelluhue, Hualane, Licanten, Rauco, Romeral, Vichuquen
Biobio	Concepcion, Coronel, Chiguayante, Lota, Penco, San Pedro de la Paz, Talcahuano, Tome, Hualpen, Hualqui, Lebu, Arauco, Canete, Curanilahue, Los Alamos, Los Angeles, Cabrero, Laja, Mulchen, Nacimiento, Yumbel Florida, Santa Juana, Contulmo, Tirua, Antuco, Negrete, Quilaco, Quilleco, San Rosendo, Santa Barbara, Tucapel, Alto Biobio
La Araucanía	Temuco, Carahue, Cunco, Freire, Lautaro, Loncoche, Nueva Imperial, Padre Las Casas, Pitrufquen, Pucon, Vilcun, Villarrica, Angol, Collipulli, Curacautin, Traiguen, Victoria, Curarrehue, Galvarino, Gorbea, Melipeuco, Perquenco, Saavedra, Teodoro Schmidt, Tolten, Ercilla, Lonquimay, Los Sauces, Lumaco, Puren, Renaico
Los Lagos	Puerto Montt, Osorno, Calbuco, Frutillar, Los Muermos, Llanquihue, Puerto Varas, Castro, Ancud, Quellon, Purranque, Cochamo, Fresia, Maullin, Chonchi, Curaco de Velez, Dalcahue, Puqueldon, Queilen, Quemchi, Quinchao, Puerto Octay, Puyehue, Rio Negro, San Juan de la Costa, San Pablo, Chaiten, Futaleufu, Hualaihue, Palena
Aysen	Coyhaique, Aysén Lago Verde, Cisnes, Guaitecas, Cochrane, Chile Chico, Rio Ibanez
Magallanes	Punta Arenas, Natales Laguna Blanca, San Gregorio, Cabo de Hornos, Porvenir, Primavera, To
Metropolitana	Santiago,Cerrillos, Cerro Navia, Conchali, El Bosque, Estacion Central, Huechuraba, Independencia, La Cisterna, La Florida, La Granja, La Pintana, La Reina, Las Condes, Lo Barnechea, Lo Espejo, Lo Prado, Macul, Maipu, Nunoa, Pedro Aguirre Cerda, Penalolen, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado,Penaflor, Pirque, San Jose de Maipo, Colina, Lampa, Tiltil, Buin, Calera de Tango, Paine, Melipilla, Curacavi, Talagante, El Monte, Isla de Maipo, Alhue, Maria Pinto, San Pedro
Los Ríos	Valdivia, Lanco, Los Lagos, Mariquina, Paillaco, Panguipulli, La Union, Rio Bueno, Corral, Mafil, Futrono, Lago Ranco
Arica y Parinacota	Arica Camarones, Putre, General Lagos
Nuble	Chillan, Chillan Viejo, Bulnes, Quillon, San Ignacio, Yungay, San Carlos, Coihueco, El Carmen, Pemuco, Pinto, Quirihue, Cobquecura, . Coelemu, Ninhue, Portezuelo, Ranquil, Treguaco, Niquen, San Fabian

Table 3: Names of all urban (red), rural (blue) and excluded (black) municipalities of each region.

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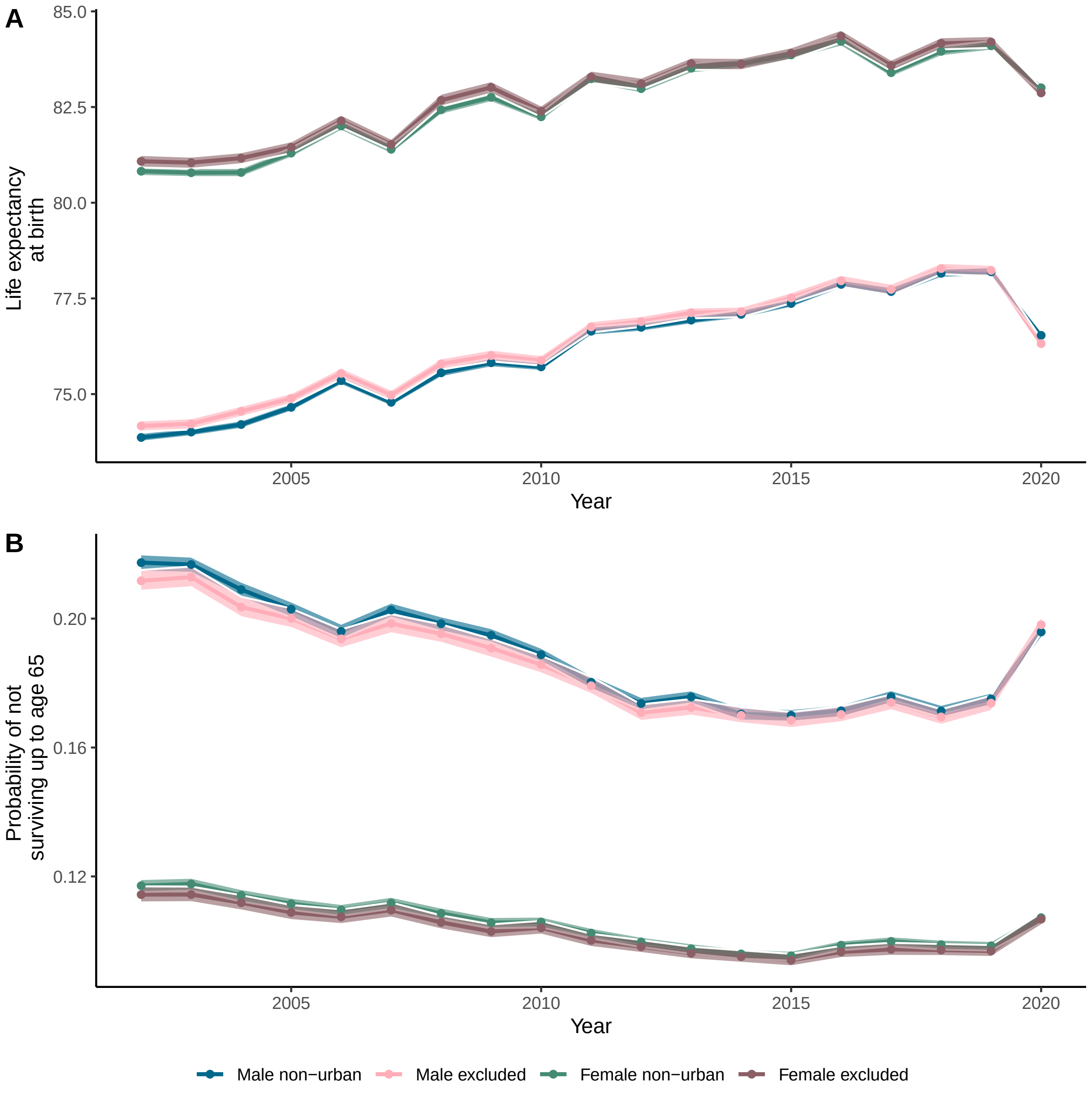

Figure 1: **A**. Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B**. Same as **A**, but with likelihood of dying before reaching 65.

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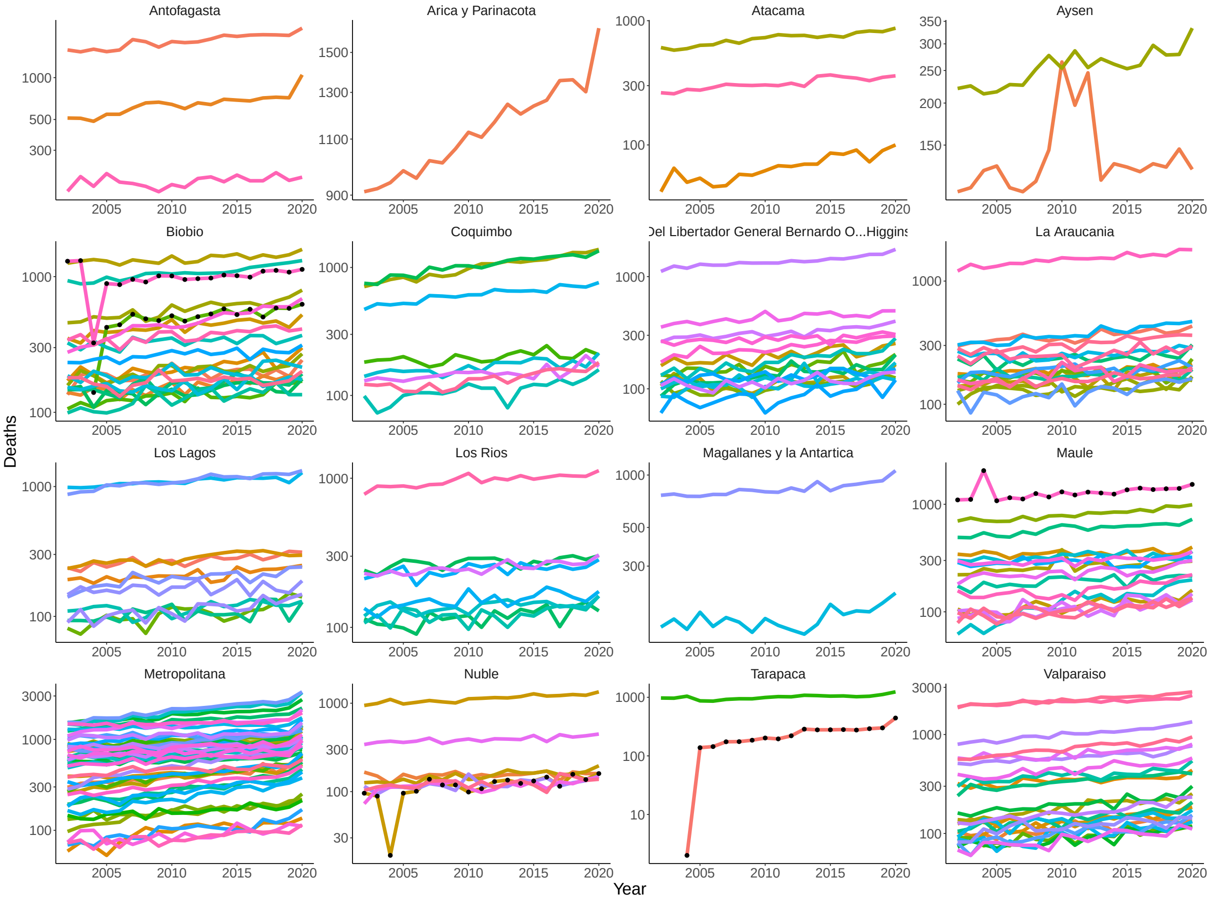

Figure 2: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring years (Talcahuano, Hualpén, Diego de Almagro, Talca, Alto Hospicio, Chillán Viejo).

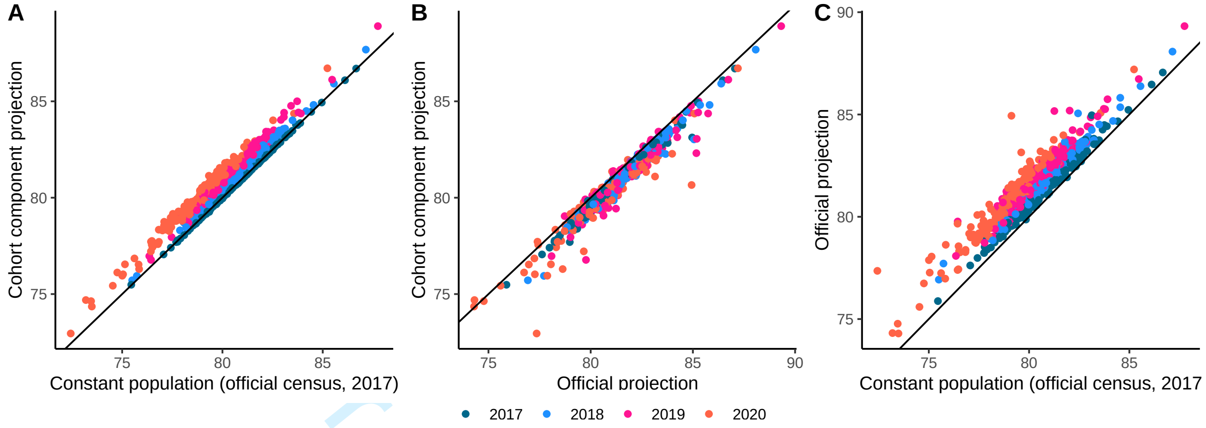

Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival projection. In **C** we compare official projection with the one that has constant population.

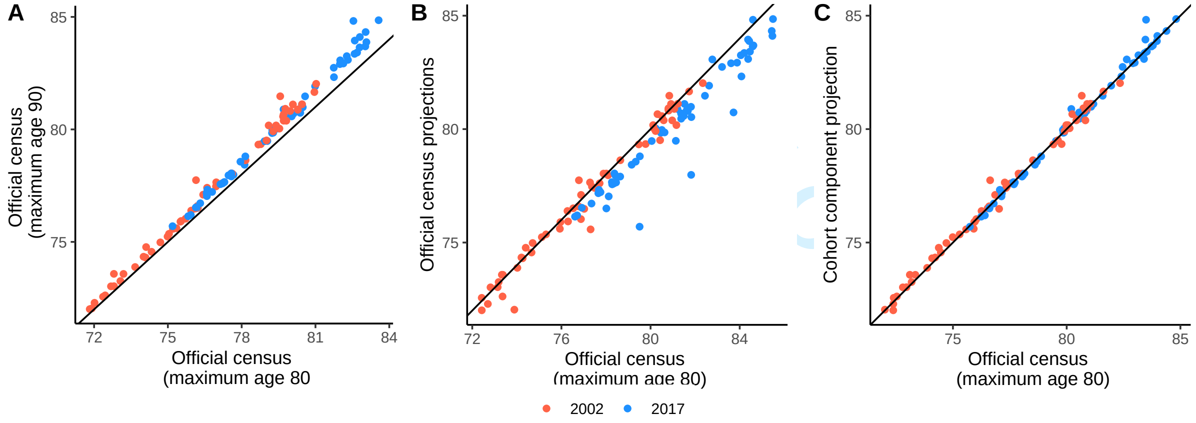

Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with official projections in that year. We note that discrepancies become more significant in year 2017, indicating the need for an alternative methodology. In **C** we compare official census (80 as cutoff age) with our cohort survival projection method. They are in close agreement, as they are both based on official census data, and not projections.

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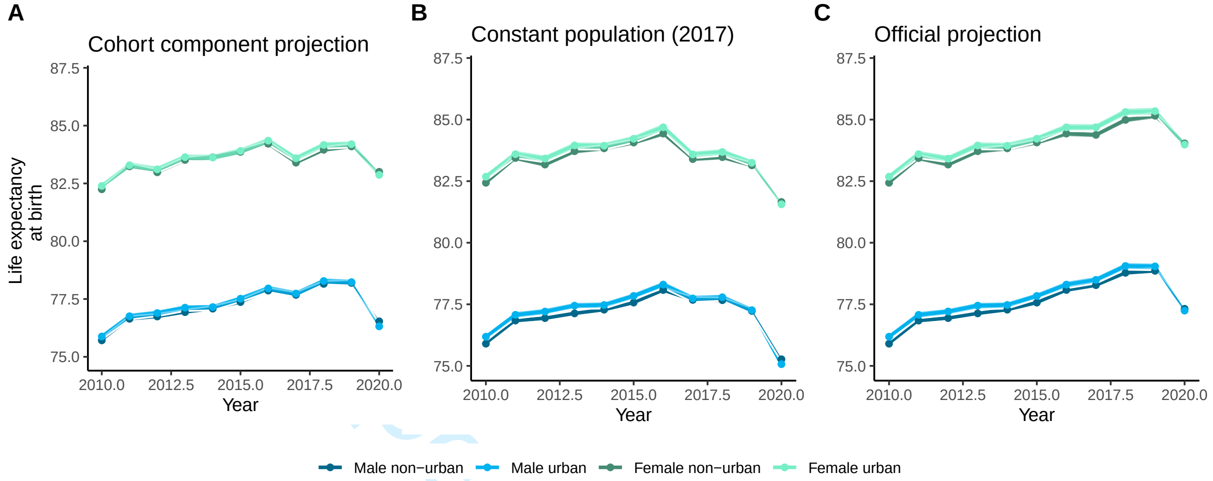

Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with **A**.

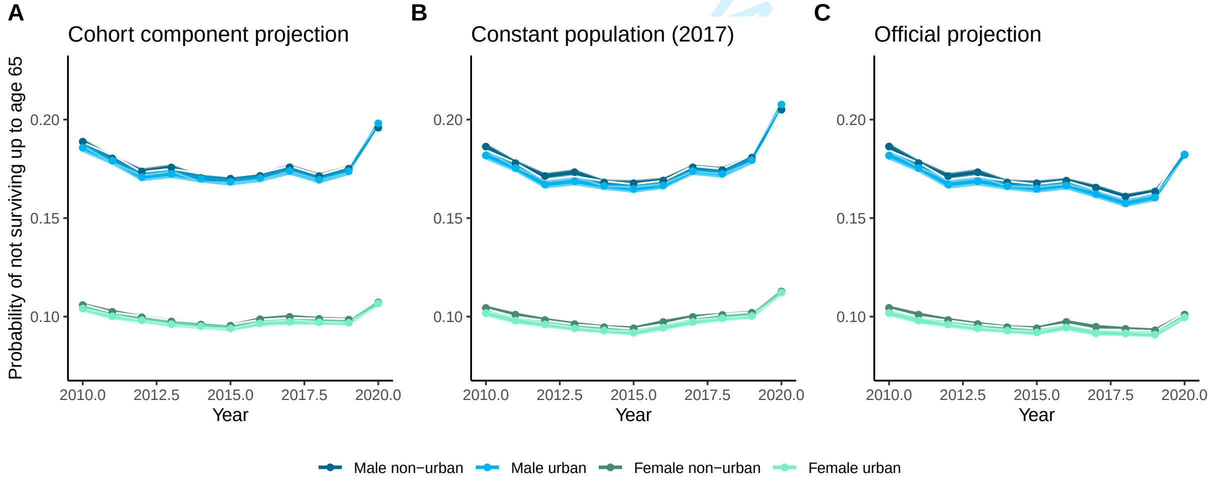

Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with **A**.

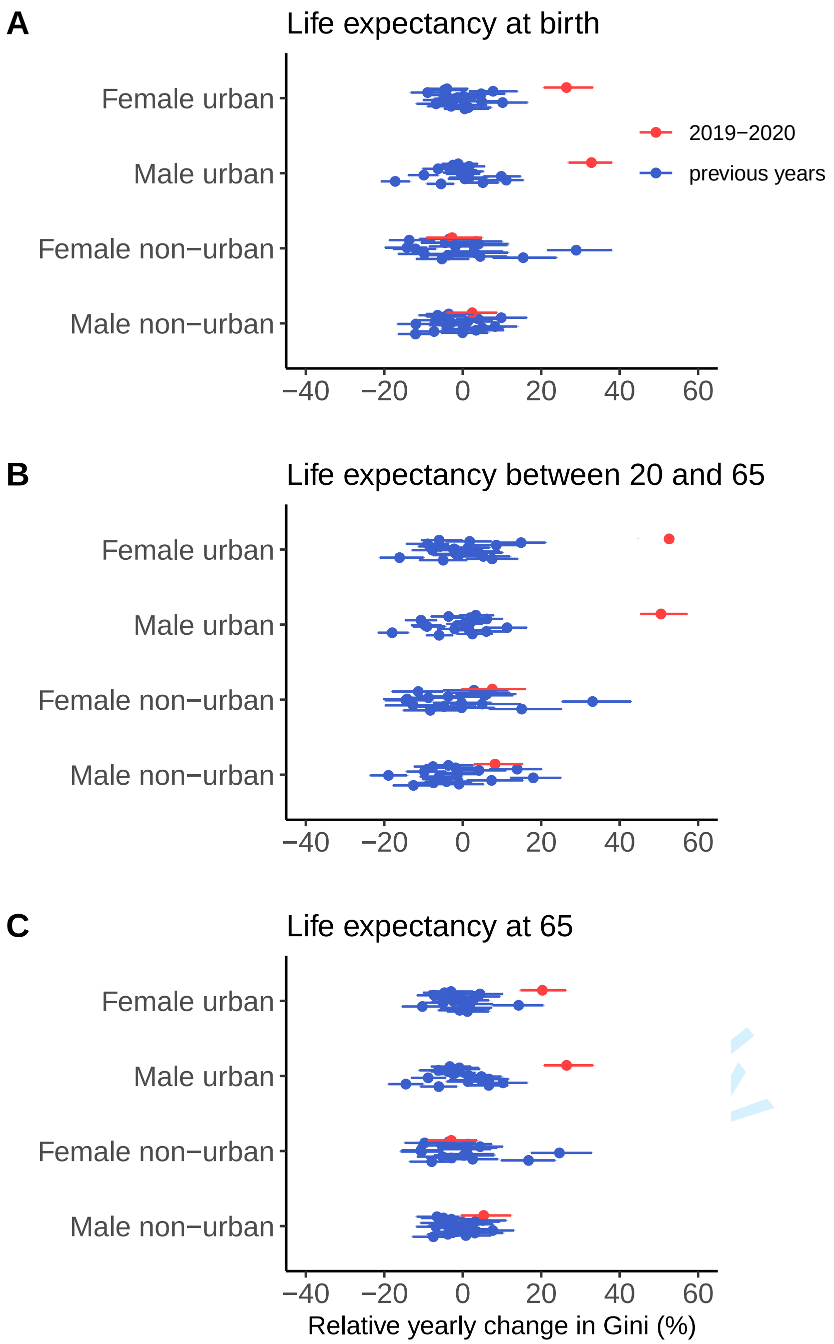

Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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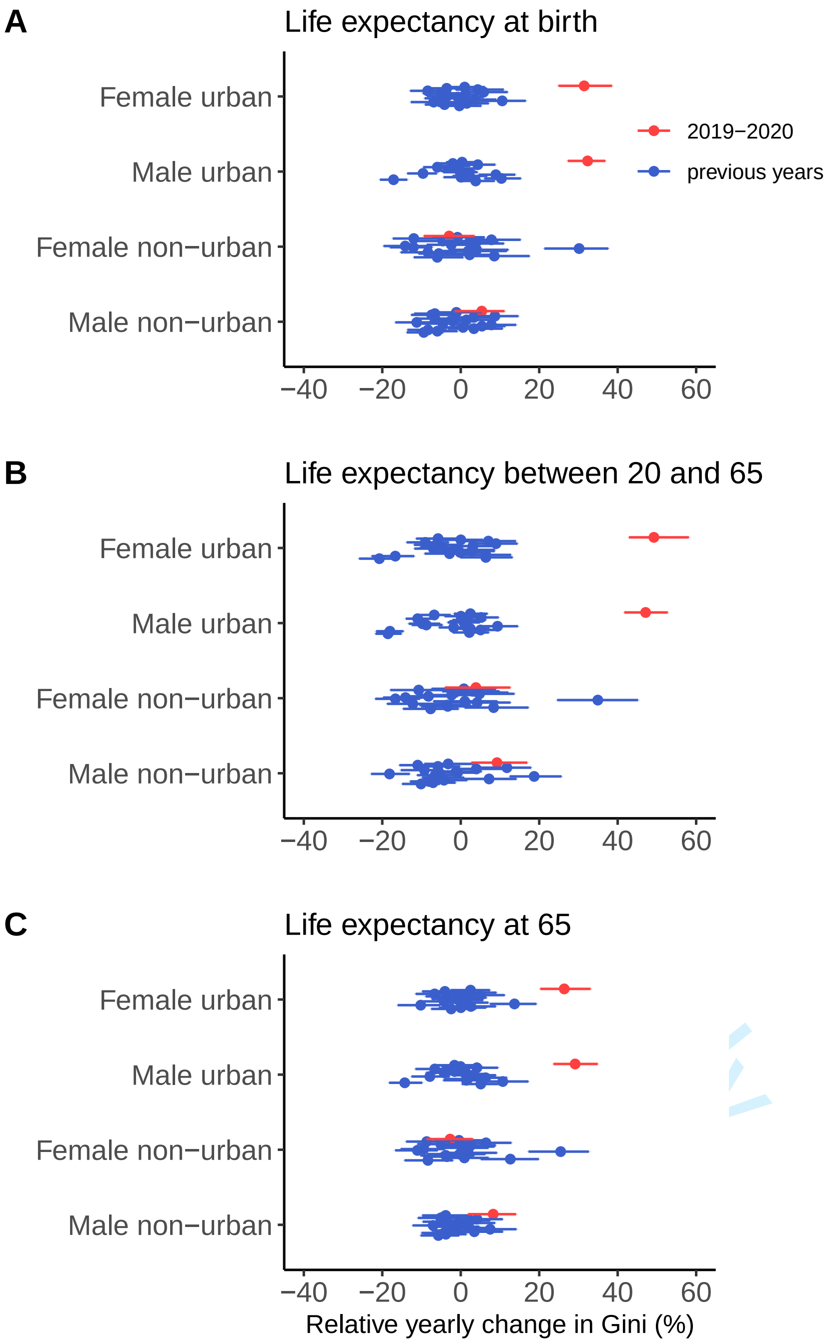

Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

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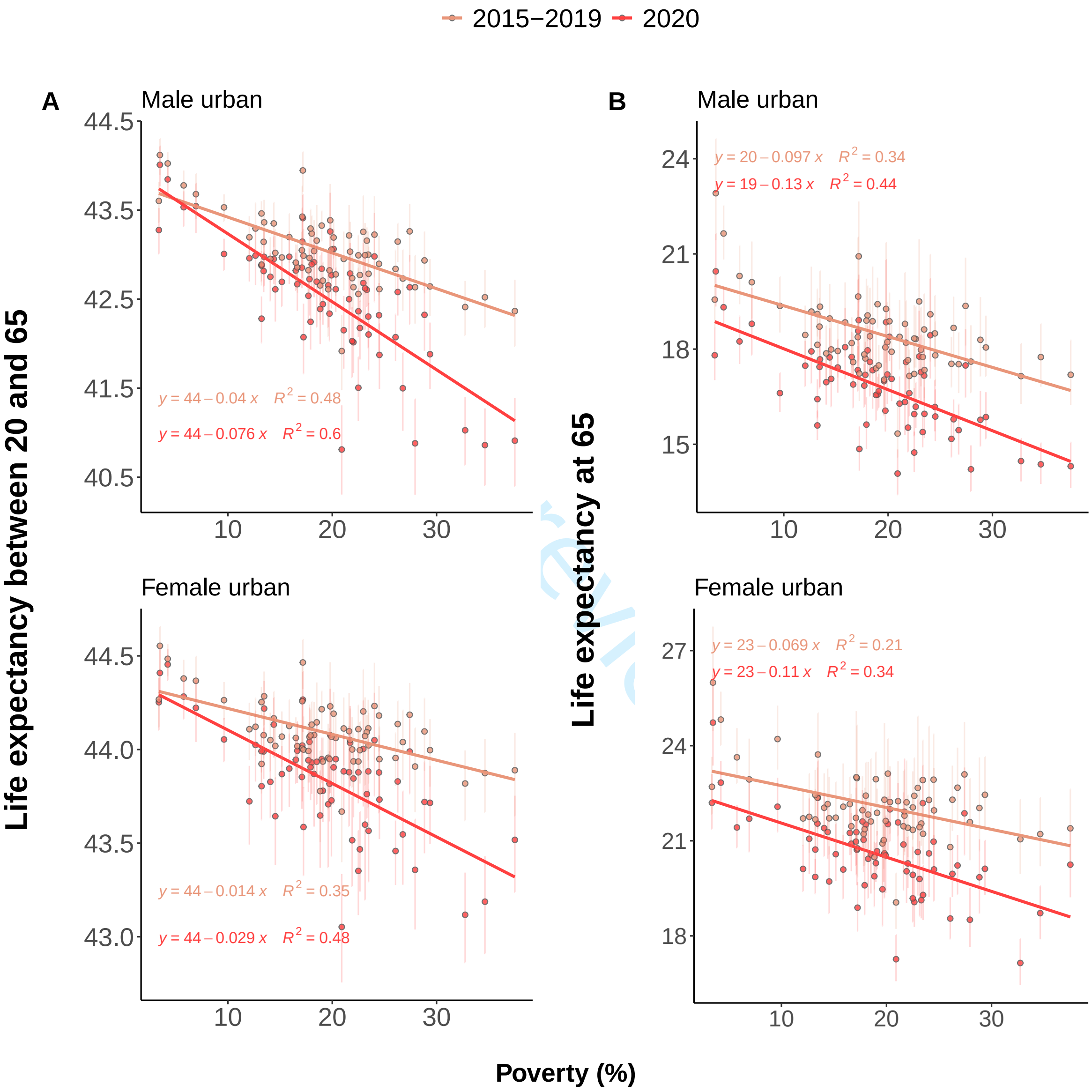

Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019 and 2020, and may be compared with Exhibit 4 in the main text.

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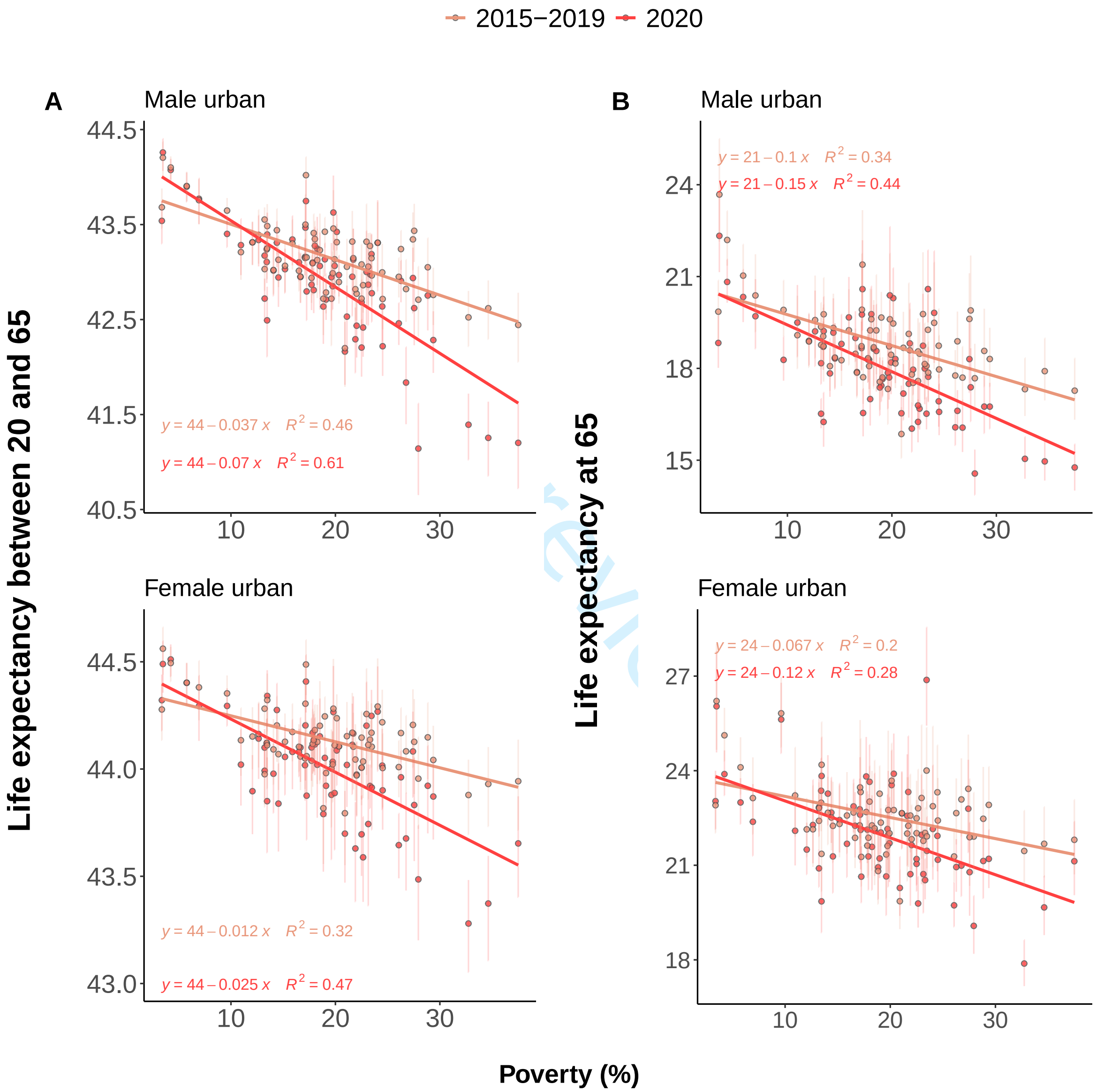

Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

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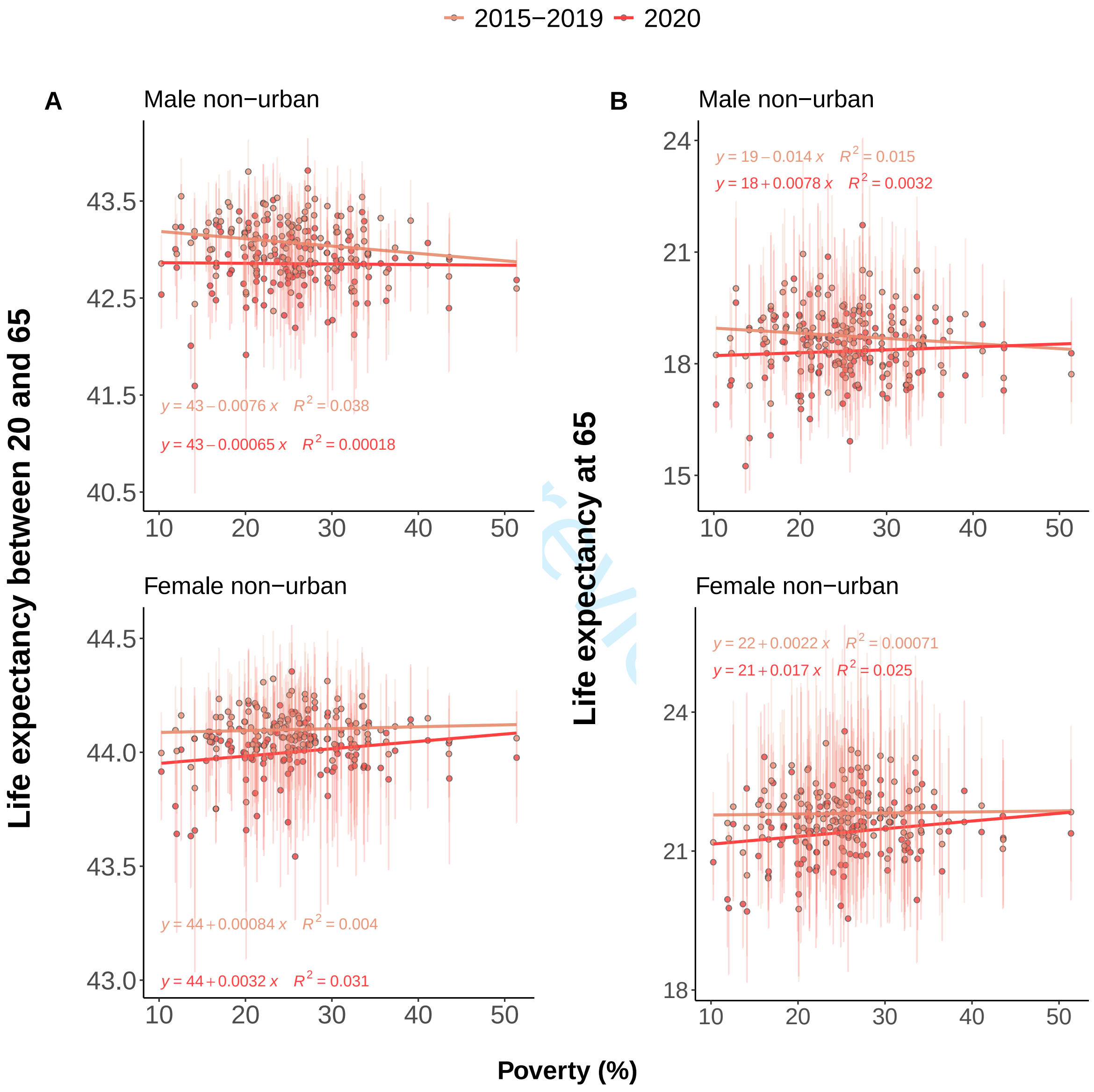

Figure 11: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

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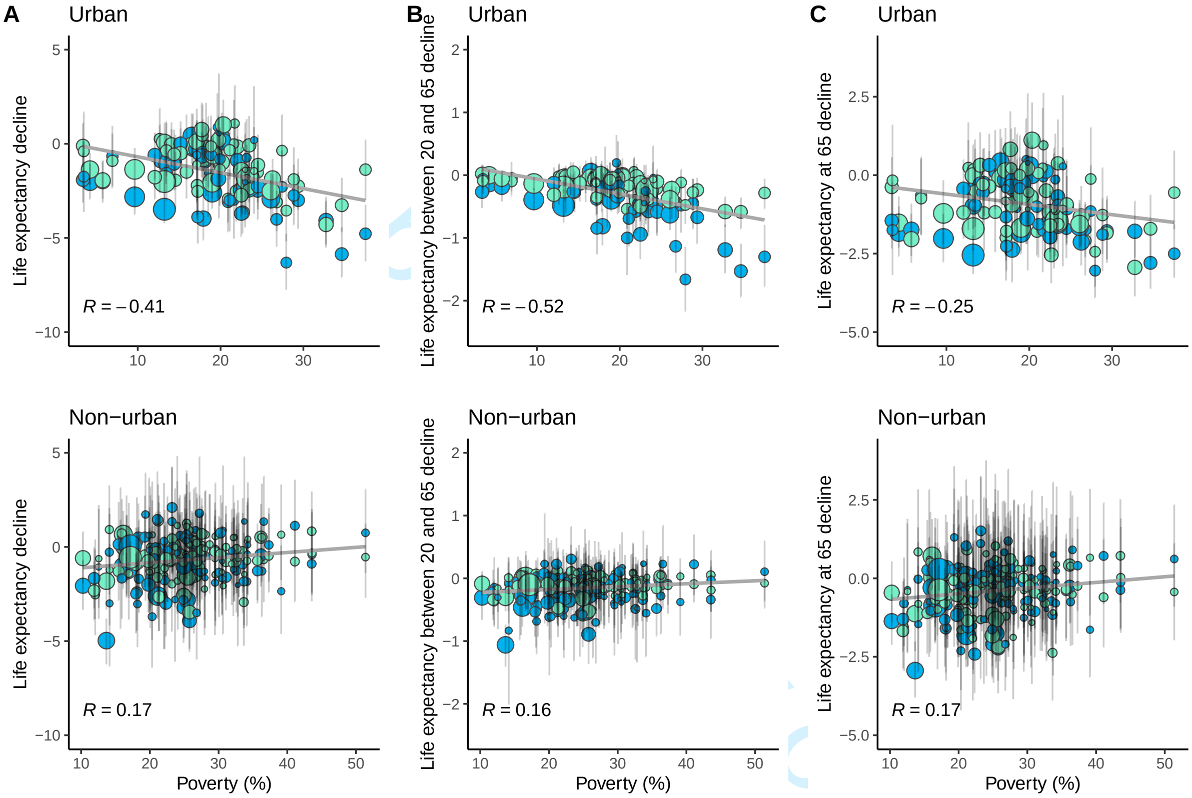

Figure 12: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and second row, respectively. A strong effect appears in urban setups, and the correlation is stronger in for life expectancy between 20 and 65.

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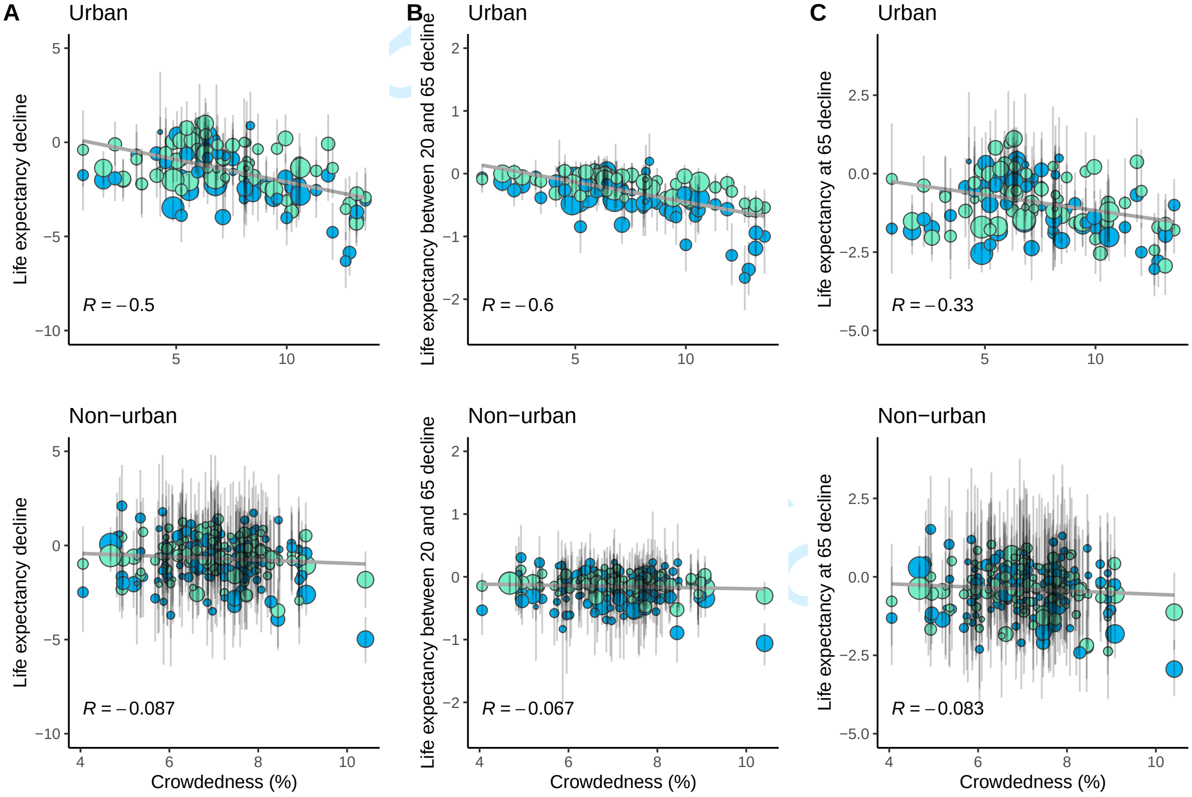
Figure 13: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in a crowded home. Each dot is a municipality, separated by gender(colors) Urban and non-urban municipalities are shown in first and second row, respectively.



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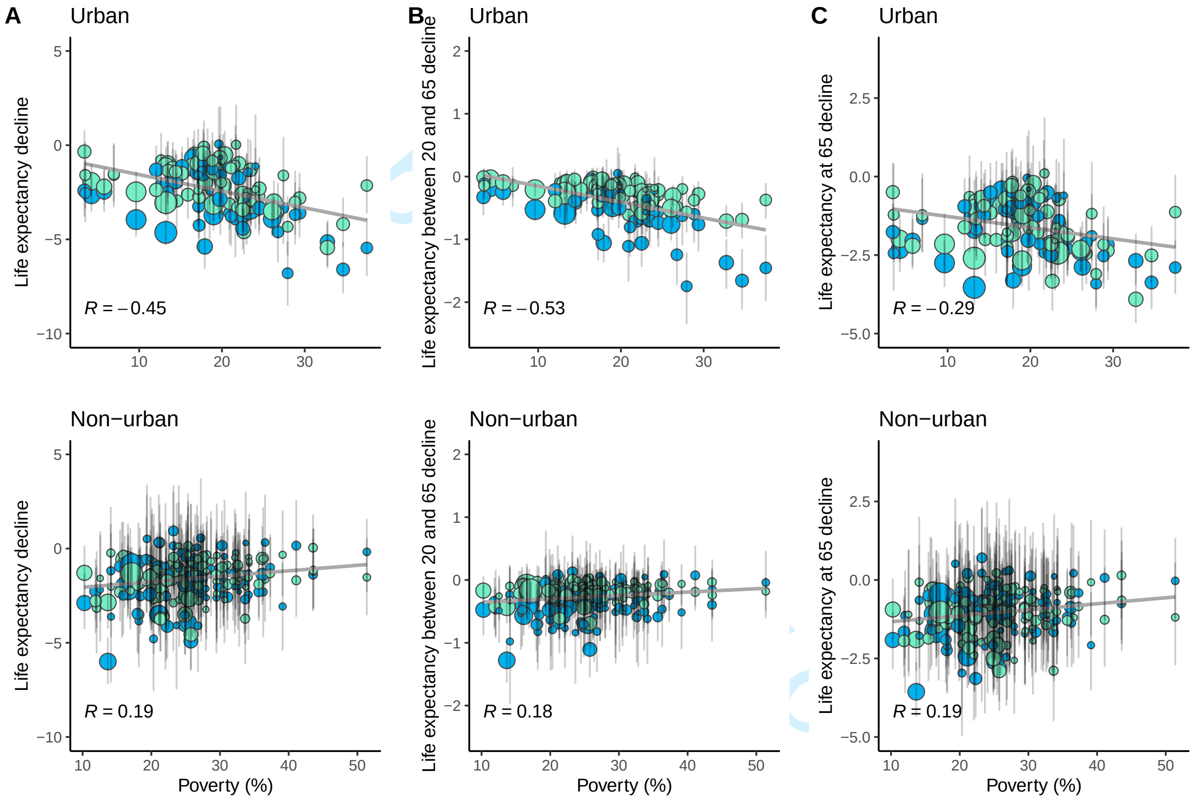

Figure 14: Same as 12 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

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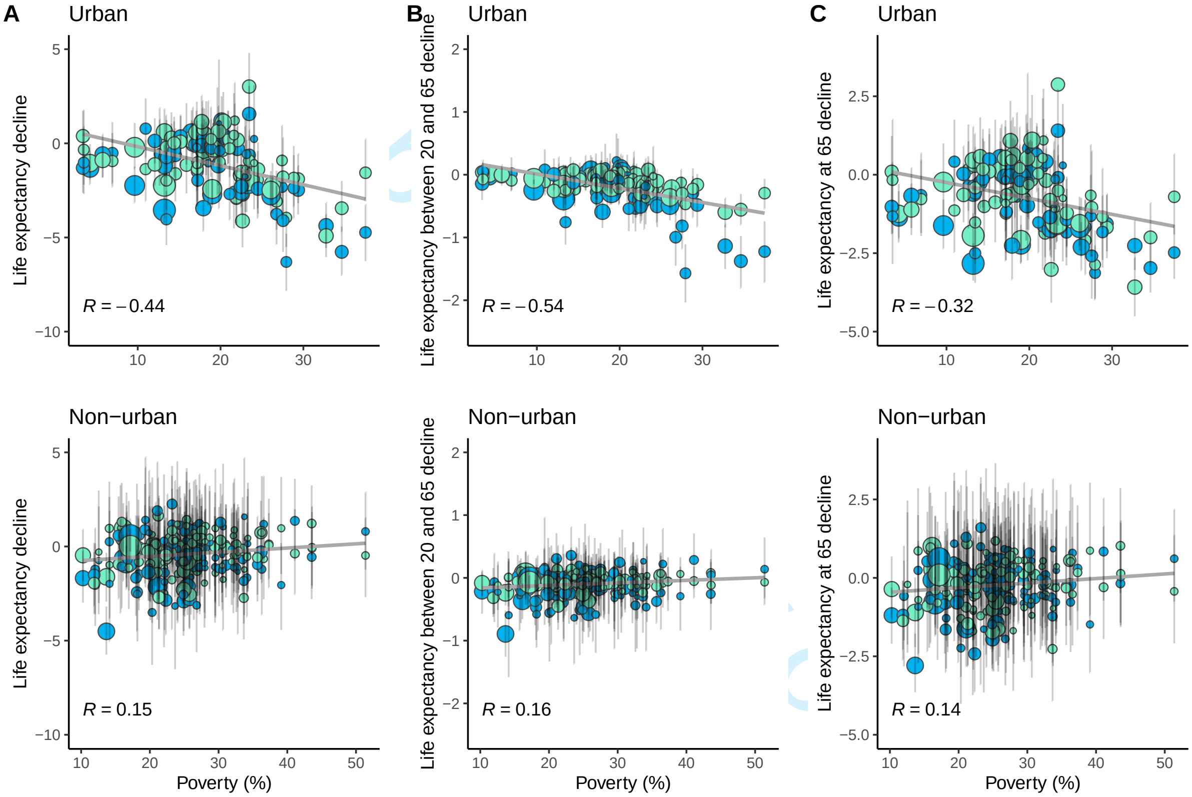

Figure 15: Same as 12 but with population estimates given by official projections.

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*8*
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	7-9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	7-9
		(*c*) Explain how missing data were addressed	7-8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	7-8
		(*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	NA
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	NA
Outcome data	15*	Report numbers of outcome events or summary measures	6

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Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-8
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-11
Discussion			
Key results	18	Summarise key results with reference to study objectives	9-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-11
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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