

BMJ Open

BMJ Open is committed to open peer review. As part of this commitment we make the peer review history of every article we publish publicly available.

When an article is published we post the peer reviewers' comments and the authors' responses online. We also post the versions of the paper that were used during peer review. These are the versions that the peer review comments apply to.

The versions of the paper that follow are the versions that were submitted during the peer review process. They are not the versions of record or the final published versions. They should not be cited or distributed as the published version of this manuscript.

BMJ Open is an open access journal and the full, final, typeset and author-corrected version of record of the manuscript is available on our site with no access controls, subscription charges or pay-per-view fees (<http://bmjopen.bmj.com>).

If you have any questions on BMJ Open's open peer review process please email info.bmjopen@bmj.com

BMJ Open

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

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-059201
Article Type:	Original research
Date Submitted by the Author:	15-Nov-2021
Complete List of Authors:	Mena, Gonzalo ; Oxford University, Statistics Aburto, José Manuel; University of Oxford, Leverhulme Centre for Demographic Science
Keywords:	COVID-19, Demography < TROPICAL MEDICINE, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

1
2
3 **Title:** The unequal impact of the COVID-19 pandemic on life
4
5 expectancy across Chile
6
7

8
9 **Authors:** Gonzalo E. Mena^{1,*}, José Manuel Aburto^{2,3}
10
11

12
13 **Affiliations:**
14

15
16
17
18 ¹Department of Statistics, University of Oxford; Oxford, UK (Email:
19 gonzalo.mena@stats.ox.ac.uk)
20
21

22
23
24 ²Leverhulme Centre for Demographic Science, Department of Sociology
25 and Nuffield College, University of Oxford; Oxford, UK (Email: jose-
26 manuel.aburto@sociology.ox.ac.uk)
27
28

29
30
31
32 ³Interdisciplinary Centre on Population Dynamics, University of
33 Southern Denmark; Odense 5000, Denmark.
34
35

36
37
38 *Corresponding author.
39
40

41
42
43
44 **Word count (main text, references):** 2921
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 **Abstract (205 words):**
4

5 **Objectives:** To quantify the effect of the COVID-19 pandemic on life
6 expectancy in Chile categorized by rural and urban, and to correlate
7 life expectancy changes with socioeconomic factors at the municipal
8 level.
9
10
11
12

13 **Design:** Retrospective cross-sectional demographic analysis using
14 aggregated data.
15
16

17 **Setting:** Vital and demographic statistics from the national
18 institute of statistics and department of vital statistics of
19 ministry of health.
20
21
22
23

24 **Participants:** Aggregated national all-cause death data stratified by
25 year (2000-2020), sex, and municipality.
26
27

28 **Main Outcome measures:** Stratified mortality rates using a Bayesian
29 methodology. With this, we assessed the unequal impact of the
30 pandemic in 2020 on life expectancy across Chilean municipalities
31 for men and women and analyzed previous mortality trends since
32 2010.
33
34
35
36
37

38 **Results:** Life expectancy declined for both men and women in
39 2020. Urban areas were the most affected, with males losing
40 1.89 and females 1.33 in 2020. The strength of the decline in
41 life expectancy correlated with indicators of social deprivation and
42 poverty. Also, inequality in life expectancy between
43 municipalities increased, largely due to excess mortality
44 among the working-age population in socially disadvantaged
45 municipalities.
46
47
48
49
50
51

52 **Conclusions:** Not only do people in poorer areas live shorter
53 lives, they also have been substantially more affected by the
54 COVID-19 pandemic, leading to increased population health
55 inequalities. Quantifying the impact of the COVID-19 pandemic
56
57
58
59
60

1
2
3 on life expectancy provides a more comprehensive picture of
4 the toll.
5
6
7
8
9

10 **Keywords:** COVID-19, Latin America, Mortality, Life expectancy,
11 Health Inequalities
12
13
14
15
16

17 **Strengths and limitations**

18
19
20

- 21 ● First study to analyze changes in life expectancy in
22 Chile with small-area resolution.
23
- 24 ● We applied a hierarchical Bayesian methodology to estimate
25 life expectancies in the past 20 years.
26
- 27 ● We show that COVID-19 led to declines in life expectancy in
28 Chile greater than a year in magnitude. These declines
29 correlated with poverty levels, indicating that socially
30 deprived populations were hit the hardest.
31
- 32 ● We also show that inequality in life expectancy between
33 municipalities increased due to excess mortality among
34 the working-age population in socially disadvantaged
35 municipalities.
36
- 37 ● The main limitation is that our estimates depend on
38 accurate small-area stratified population estimates. We
39 implemented several estimates and showed that our
40 findings are robust to the choice of them.
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57

58 **Main Text**
59
60

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

1
2
3 been on life expectancy at a more granular level of geography and by
4
5 population subgroups in Chile.
6
7

8
9 In this context of persistent and pervasive health inequalities,
10 varied mortality impacts by age and sex, and regional variation, it
11 is imperative to analyze how has life expectancy been affected
12 differently across Chile. Due to the heightened risk to COVID-19 and
13 mortality of disadvantaged populations, most deprived areas may have
14 experienced greater losses in life expectancy, especially among men.
15 Similarly, since rural and urban areas may be affected differently,
16 and mortality increased among young working-age men, we hypothesize
17 that younger age excess mortality will have a substantial effect on
18 life expectancy losses potentially increasing disparities at the
19 municipality level. This hypothesis is supported by evidence from
20 Chile's capital suggesting that urban and more crowded areas have
21 experienced worse health outcomes during the pandemic.^{7,11}
22 Alternatively, since death rates increased exponentially with age
23 and losses in life expectancy in low mortality countries have been
24 attributed mostly to mortality above age 60,⁶ another hypothesis is
25 that the pandemic in 2020 was such a strong shock that excess
26 mortality differentials decreased, leading to reducing inequalities
27 between municipalities.
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51 This article contributes towards a more comprehensive understanding
52 of the COVID-19 pandemic's burden on population health by estimating
53 life expectancy across Chilean municipalities by sex using a
54 powerful Bayesian methodology.¹² We contextualize our results with
55 past trends of progress and disparities in life expectancy, and
56
57
58
59
60

1
2
3 categorize our findings by urban vs non-urban areas. Our study is a
4
5 step towards explaining the varied impacts of the pandemic by
6
7 analyzing trends in life expectancy over age at a more granular
8
9 level and by correlating life expectancy losses with indicators of
10
11 poverty in Chile.
12
13
14
15
16

17 **Study Data and Methods**

21 **Data**

22
23
24
25
26 We used data on births and deaths by age, sex and municipality from
27
28 publicly available vital statistics.¹³ These data were complemented
29
30 with official population counts by age (single years of age from 0
31
32 to 89 and collapsed in 90+), sex and municipality from the 2002 and
33
34 2017 censuses available from the National Institute of Statistics
35
36 (INE).¹⁴ We also used official population projections between 2002
37
38 and 2020 centered at the 2017 census.¹⁵ Unlike censuses themselves,
39
40 these projections collapsed all ages greater than 80 in one single
41
42 group. We only observed minor changes in our estimates based on
43
44 whether the open ended interval started at 80 or 90, but we did
45
46 observe that life expectancy estimates based on 2017 projections
47
48 were substantially higher than the ones based on the 2017 census. We
49
50 explain this by a possible inadequacy of the official projection for
51
52 later years. Because of this reason, we considered two alternative
53
54 population estimates for 2017 onwards. The first one assumes that
55
56 population counts remain fixed for years 2018, 2019 and 2020. In the
57
58 second one, we projected forward the population using the cohort
59
60

1
2
3 component method¹⁶ with 2017 as baseline assuming zero migration. We
4
5 also used census data to classify municipalities as urban or non-
6
7 urban. (See Supplementary Tables 1-3).¹⁷ Data on poverty and
8
9 crowdedness were taken from the CASEN survey by the Chilean Ministry
10
11 of Social Development and Family.¹⁸
12
13

14 15 ***Mortality estimation*** 16

17
18
19 Age specific death rates for each municipality by sex were estimated
20
21 implementing a recently developed methodology¹² based on a
22
23 hierarchical Bayesian model¹⁹ using population and death counts.¹⁷
24
25 There are two main advantages to this Bayesian methodology: first,
26
27 by sharing information across global variables, it is possible to
28
29 smooth out the noisy estimates that would otherwise be obtained if
30
31 we relied only on empirical counts. This is important because of the
32
33 increased likelihood of low death counts on each strata in small
34
35 municipalities. Second, by appealing to the Bayesian methodology we
36
37 obtain credible intervals for each of our estimates.
38
39
40
41

42 43 ***Life tables*** 44

45
46 Life tables were calculated using the age specific death rates
47
48 estimated in the Bayesian procedure following standard techniques.¹⁶
49
50 From these, period life expectancy at birth, temporary life
51
52 expectancy between ages 20 and 65, and remaining life expectancy at
53
54 age 65 were subtracted. Life expectancy at birth refers to the
55
56 average years a cohort of newborns is expected to live given the
57
58 current mortality conditions. Similarly, life expectancy at age 65
59
60

1
2
3 refers to the average years individuals aged 65 are expected to live
4
5 if they were to experience the current mortality conditions
6
7 throughout their lives. Given the emerging evidence about how
8
9 younger age groups below age 65 have also been affected by the
10
11 pandemic in the context of Chile, we constructed a measure to
12
13 capture average longevity over working ages through temporary life
14
15 expectancy. Temporary life expectancy between ages 20 and 65 refers
16
17 to the average years lived between these ages given prevalent
18
19 mortality conditions.²⁰ For example, if no one were to die between
20
21 these ages, then the temporary life expectancy would be the full 45
22
23 years. To complement our analysis we also consider the probability
24
25 of not reaching age 65 as an indicator of premature mortality. As a
26
27 measure of inequality between municipalities we calculated the Gini
28
29 coefficient of life expectancy across municipalities.²¹ The Gini
30
31 coefficient is a standard indicator of inequality employed in social
32
33 sciences. In the context of this paper, the Gini coefficient
34
35 expresses the degree of inequality in life expectancy across
36
37 municipalities.
38
39
40
41
42

43 ***Limitations***

44
45
46 This study had several limitations. First, while Chile's vital
47
48 registration is one of the most reliable in Latin America, there are
49
50 likely to be inaccuracies in mortality registration due to age
51
52 misreporting and coverage across municipalities, as well as
53
54 systematic age overstatement.²² Delays in recording deaths may lead
55
56 to incompleteness issues especially in urban areas. Our results on
57
58 life expectancy declines and mortality inequalities may be
59
60

1
2
3 considered a lower bound because of these issues. The effect of
4 systematic age overstatement is likely to affect our results too.
5
6 However, there is no information on what the age pattern of
7
8 overstatement is during the pandemic. To mitigate these inaccuracies
9
10 and their effects on our life expectancy estimates, we used a
11
12 hierarchical Bayesian model that helped to retrieve a reasonable
13
14 mortality profile across regions. Another limitation is that because
15
16 of the low number of deaths observed in some municipalities, the
17
18 degree of uncertainty around the estimates was very high, not
19
20 allowing us to include them in our analysis with confidence. We
21
22 excluded municipalities by sex with less than 16,000 people (as per
23
24 the 2017 census), as we observed that life expectancy estimates were
25
26 unstable even with our adopted Bayesian methodology. However, we
27
28 grouped them together and reproduced all results to avoid systematic
29
30 exclusion. Results were consistent and are shown in Supplementary
31
32 Figure 2.¹⁷ Almost all of these were all non-urban municipalities.
33
34 Some other municipalities were excluded based on a visual inspection
35
36 of mortality trends that were clearly indicative of coding errors in
37
38 the mortality database (see Supplementary Figure 1) Despite these
39
40 limitations, we used the most reliable data for Chile and state-of-
41
42 the-art methodologies to gauge mortality dynamics across Chile.
43
44 Finally, our results are limited in that stratified population
45
46 counts are typically model-based estimates (except at census years),
47
48 and might be biased. We studied the effect of alternative population
49
50 estimates in final outcome measures, as described in the Supplement
51
52 (Figures 3-17).

53 54 55 56 57 58 59 60 **Study Results**

1
2
3
4
5 ***Trends in life expectancy at birth and survivorship below age 65.***
6
7
8

9 Men and women from both urban and non-urban areas experienced steady
10 increases in life expectancy at birth from 2010 to 2019. Women
11 showed higher life expectancy at birth than men in all groups. In
12 contrast, higher mortality during 2020 led to sharp decreases in
13 life expectancy at birth (Figure 1). Life expectancy among men in
14 urban and non-urban areas declined by 1.89 (1.68,2.09) and 1.66
15 (1.5,1.8) years, respectively. Among women, life expectancy losses
16 were 1.33 (1.11,1.55) and 1.10 (0.918,1.28), respectively. The
17 magnitude of the decline from 2019 to 2020 offset most gains in life
18 expectancy experienced in the last decade, especially in urban
19 areas. In fact, 68% of the municipalities analyzed ended up with
20 lower life expectancy than in 2015, and this number rose to 75% in
21 urban municipalities.
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37

38 Decreases in the probability of surviving to age 65 (Figure 2)
39 indicate that these declines cannot be fully attributed to increased
40 mortality in older age groups only. While mortality above age 65 has
41 been documented as one of the main contributors to declines in life
42 expectancy internationally, substantial increases in mortality below
43 age 65 are apparent in our results, especially among men in urban
44 areas.
45
46
47
48
49
50
51
52
53
54

55 ***Changes in disparities in life expectancy during the COVID-19***
56 ***pandemic in 2020***
57
58
59
60

1
2
3 Figure 3 shows the year-to-year relative changes of the Gini
4 coefficient as a measure of inequality in life expectancy across
5 municipalities. Panel A refers to life expectancy at birth, panel B
6 to life expectancy between age 20 and 65, and panel C to life
7 expectancy at age 65. From our results it emerges that inequality
8 increased substantially in urban areas from 2019 to 2020 in
9 comparison with previous years, with changes oscillating around 25%.
10 The magnitude of increase is much larger in men and women's life
11 expectancy between ages 20 and 65 from urban areas (50.9% and 50.6%
12 for men and women respectively). Altogether, these results indicate
13 not only that mortality during 2020 became more unequal, but that
14 this inequality was driven mostly by the younger age group.
15 Supplementary Figures 14-17 show that larger variation in 2020
16 compared with previous years was driven by lower values of life
17 expectancy.

18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36 To better understand the factors driving this spike in inequality,
37 we investigated how declines in life expectancy during 2020
38 correlated with social deprivation indicators including poverty and
39 crowdedness focusing only on mortality above age 20 across urban
40 areas. Figure 4 shows the relationship between poverty and life
41 expectancy between age 20 and 65 and life expectancy at age 65. To
42 underscore how the relationship changed in the course of 2020, we
43 stratified the results juxtaposing the previous five years (2015-19)
44 with 2019-20. Results show a strong historical negative correlation
45 between life expectancies in both age groups, sexes and poverty
46 levels. Males in the top poverty decile have a 4.39 expectancy lower
47 life expectancy than in the bottom decile. They also live on average
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 0.92 less years between 20 and 65, and 2.22 from 65 onwards. For
4
5 females, these numbers are 2.51, 0.31 and 1.55 years. During 2020,
6
7 the slope became more negative, suggesting that those municipalities
8
9 with higher levels of poverty experienced greater losses in life
10
11 expectancy. This dependency was stronger in the younger age group.
12
13

14
15 In contrast, while life expectancy at 65 declined during 2020, this
16
17 decline was less unequal over the poverty gradient, consistent with
18
19 the hypothesis that this group contributed less to inequality in
20
21 changes in life expectancy. To formalize these observations, we
22
23 performed regression analyses to model the interactions between year
24
25 and poverty level through varying intercepts and slopes. We only
26
27 found significant changes in slope for average years lived between
28
29 20 and 65. For males, this translated into an additional difference
30
31 of 0.78 years between the highest and lowest poverty deciles ($p=0$).
32
33 For females, this difference was 0.3 ($p<0.001$)
34
35
36
37

38 **Discussion**

39
40
41
42 Urban areas that are exposed to higher poverty or social
43
44 disadvantages experienced larger losses in life expectancy during
45
46 the COVID-19 crisis in 2020 in Chile. Our results reveal that losses
47
48 were unevenly shared across municipalities, over age, and by sex,
49
50 leading to increasing inequality in life expectancy across regions
51
52 in Chile. Moreover, consistent with previous research on increased
53
54 mortality at younger ages in 2020 in deprived municipalities in
55
56 Chile's capital,⁷ our research shows that working age mortality was
57
58
59
60

1
2
3 one of the main drivers of increasing inequality in life expectancy
4
5 across Chile.
6
7
8

9 Analysis of life expectancy in 2020 compared with the previous five
10 years (2015-19) show that poorer urban municipalities suffered a
11 double burden. Not only did they show lower levels of life
12 expectancy but they also experienced greater losses in life
13 expectancy. This is consistent with previous research documenting
14 larger mortality increases for the lower educated groups in Chile's
15 capital.²³ Furthermore, when we disaggregate by age groups, we
16 observe that the association between life expectancy for working age
17 individuals (between ages 20 and 65) and levels of poverty became
18 stronger compared to previous years. This is a surprising finding
19 given that previous evidence had documented a positive association
20 between income and life expectancy at retirement.²⁴ This suggests
21 that even if the burden of mortality during the COVID-19 crisis has
22 been concentrated at older ages,²⁵ contributing substantially to life
23 expectancy declines during 2020,⁶ inequalities in life expectancy
24 were largely driven by increased mortality in working ages at higher
25 levels of poverty. A potential explanation is that the working age
26 population's availability to work from home and be less exposed to
27 heightened risk of COVID-19 and its consequences varies across
28 municipalities. Deprived populations in Chile's capital experienced
29 higher fatality rates as a consequence of worse baseline individual
30 health status and to an overwhelmed healthcare system.⁷ Similarly,
31 evidence from the US suggests that those individuals with less
32 availability to work from home had higher death rates compared to
33 those that could afford working from home in 2020.²⁶
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5 An open question is whether this sudden increase in inequality
6 amounts to a shock that will be followed by a recovery to pre-
7 pandemic levels, or whether these changes will persist in the long
8 term. Beyond the immediate increase in premature mortality, this is
9 relevant because failing to acknowledge inequalities in mortality
10 may compromise the progressiveness and actuarial fairness of social
11 security and public pension systems in the long term,^{27,28} which could
12 be translated into higher mortality in the future. Similarly, the
13 scars left by the pandemic, including a weak health system, may
14 increase mortality from multiple causes of death. For example,
15 postponed cancer treatments and failure to detect other chronic
16 degenerative diseases timely may lead to lower levels of life
17 expectancy in the long term than it was projected. This highlights
18 the need for accurate and timely data on other causes of death.
19 Future analysis should focus on analyzing the consequences of the
20 COVID-19 pandemic, including multiple causes of death and diseases
21 to study the direct effects from COVID-19 mortality as well as the
22 indirect effects through other pathways of diseases and conditions.²⁹
23 Our research, in this sense, provides a first outlook by focusing on
24 all-cause mortality.
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48

49 As shown by our results, the case of Chile underscores the dire
50 widening of an already large mortality gap between those living in
51 deprived conditions and those living with higher income during the
52 COVID-19 crisis. Evidence shows that the health consequences of
53 external shocks such a pandemic or an economic crisis are not spread
54 equally across social deprivation levels.³⁰ The COVID-19 pandemic
55
56
57
58
59
60

1
2
3 reminds us of the ever-present risk of such events, whose cumulative
4 effect may partially explain the ever-existing gaps in mortality.
5
6 Therefore, the way that this crisis has exposed the vulnerabilities
7 of socially deprived populations is a call to challenge the
8
9 monolithic view of a country's demographics in the design of social
10 security systems. New strategies incorporating a public health
11 perspective that considers widening inequalities should be
12
13 implemented to minimize the effects of the COVID-19 pandemic on the
14 health status of the Chilean population both immediately and in the
15 long term.
16
17
18
19
20
21
22
23
24
25
26
27

28 **Acknowledgements:** We are grateful to Alberto Palloni for comments on
29 earlier versions of the manuscript, and to Monica Alexander and
30 Ameer Dharamshi for sharing their code related to reference 12.
31
32
33
34
35

36 **Funding:** This work was supported by the British Academy's Newton
37 International Fellowship (JMA) and a ROCKWOOL Foundation's grant on
38 excess deaths (JMA).
39
40
41
42
43
44

45 **Data availability statement:** *The data underlying this article are*
46 *available in The datasets were derived from sources in the public*
47 *domain: <https://deis.minsal.cl/>.*
48
49
50
51
52

53 **Author contributions:** GM, data curation, software, validation GM and
54 JMA formal analysis, investigation, conceptualisation, methodology,
55 project administration, resources, validation, visualisation,
56
57
58
59
60

1
2
3 writing (original draft), and writing (review & editing) JMA funding
4
5 acquisition, supervision
6
7
8

9 **Ethics approval:** This research project does not require ethics
10 approval as it uses only macro data that are freely available
11 online.
12
13
14

15
16
17 **Conflict of interest:** None declared.
18

19 **References**

- 20
21
22
23
24 1. World Health Organization. *The World health report : 2000 : Health systems : improving*
25 *performance*. (World Health Organization, 2000).
26
27
28 2. Alvarez, J.-A., Aburto, J. M. & Canudas-Romo, V. Latin American convergence and
29 divergence towards the mortality profiles of developed countries. *Population Studies* **74**,
30 75–92 (2020).
31
32
33 3. Castanheira, H. C., Costa Monteiro da Silva, J. H., Del Popolo, F., Guiomar, B. & Saad,
34 P. COVID-19 mortality. Evidence and scenarios. *Latin American and Caribbean*
35 *Demographic Centre (CELADE)-Population Division of ECLAC, United Nations* (2021).
36
37
38 4. Dyer, O. Covid-19 hot spots appear across Latin America. *BMJ* **369**, m2182 (2020).
39
40
41 5. Latin America and the Caribbean surpass 1 million COVID deaths - PAHO/WHO | Pan
42 American Health Organization. [https://www.paho.org/en/news/21-5-2021-latin-america-](https://www.paho.org/en/news/21-5-2021-latin-america-and-caribbean-surpass-1-million-covid-deaths)
43 [and-caribbean-surpass-1-million-covid-deaths](https://www.paho.org/en/news/21-5-2021-latin-america-and-caribbean-surpass-1-million-covid-deaths).
44
45
46
47 6. Aburto, J. M. *et al.* Quantifying impacts of the COVID-19 pandemic through life
48 expectancy losses. *medRxiv* 2021.03.02.21252772 (2021)
49
50
51
52
53
54
55
56
57 7. Mena, G. E. *et al.* Socioeconomic status determines COVID-19 incidence and related
58 mortality in Santiago, Chile. *Science* (2021) doi:10.1126/science.abg5298.
59
60
61 8. Millalen, P., Nahuelpan, H., Hofflinger, A. & Martinez, E. COVID-19 and Indigenous

- 1
2
3 peoples in Chile: vulnerability to contagion and mortality. *AlterNative: An International*
4 *Journal of Indigenous Peoples* **16**, 399–402 (2020).
5
6
7
8 9. Lima, E. *et al.* Exploring excess of deaths in the context of covid pandemic in selected
9 countries of Latin America. (2020) doi:10.31219/osf.io/xhkp4.
10
11
12 10. Cifuentes, M. P., Rodriguez-Villamizar, L. A., Rojas-Botero, M. L., Alvarez-Moreno, C. A.
13 & Fernández-Niño, J. A. Socioeconomic inequalities associated with mortality for
14 COVID-19 in Colombia: a cohort nationwide study. *J Epidemiol Community Health* **75**,
15 610–615 (2021).
16
17
18
19
20 11. OECD. 1. The COVID-19 crisis in urban and rural areas | OECD Regional Outlook 2021 :
21 Addressing COVID-19 and Moving to Net Zero Greenhouse Gas Emissions | OECD
22 iLibrary. [https://www.oecd-ilibrary.org/sites/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
23 [en/index.html?itemId=/content/component/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
24 [en/index.html?itemId=/content/component/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
25 [en/index.html?itemId=/content/component/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
26 [en/index.html?itemId=/content/component/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
27 [en/index.html?itemId=/content/component/c734c0fe-](https://www.oecd-ilibrary.org/sites/c734c0fe-en/index.html?itemId=/content/component/c734c0fe-en)
28
29 12. Alexander, M., Zagheni, E. & Barbieri, M. A Flexible Bayesian Model for Estimating
30 Subnational Mortality. *Demography* **54**, 2025–2041 (2017).
31
32
33 13. Departamento de Estadísticas Vitales. Departamento de Estadísticas e Información de
34 Salud. <https://deis.minsal.cl/>.
35
36
37 14. Instituto Nacional de Estadísticas de Chile. Instituto Nacional de Estadísticas de Chile.
38 <https://redatam-ine.ine.cl/>.
39
40
41 15. INE. Proyecciones de Población. *Default*
42 <http://www.ine.cl/estadisticas/sociales/demografia-y-vitales/proyecciones-de-poblacion>.
43
44
45 16. Preston, S. H., Heuveline, P. & Guillot, M. *Demography, Measuring and Modeling*
46 *Population Processes*. (Wiley Blackwell, 2001).
47
48
49 17. Health Affairs. Health Affairs supplement. (2021).
50
51
52 18. Ministerio de Desarrollo Social. Observatorio Social - Ministerio de Desarrollo Social y
53 Familia. <http://observatorio.ministeriodesarrollosocial.gob.cl/encuesta-casen>.
54
55
56 19. Gelman, A., Carlin, J. B., Stern, H. S. & Rubin, D. B. *Bayesian Data Analysis*. (Chapman
57 and Hall/CRC, 1995). doi:10.1201/9780429258411.
58
59
60 20. Arriaga, E. E. Measuring and Explaining the Change in Life Expectancies. *Demography*

- 1
2
3 **21**, 83–96 (1984).
4
5 21. Gini, C. Measurement of Inequality of Incomes. *The Economic Journal* **31**, 124–126
6
7 (1921).
8
9 22. Palloni, A., Beltrán-Sánchez, H. & Pinto, G. Estimation of older-adult mortality from
10 information distorted by systematic age misreporting. *Population Studies* **0**, 1–18 (2021).
11
12 23. Bilal, U., Alfaro, T. & Vives, A. COVID-19 and the worsening of health inequities in
13 Santiago, Chile. *Int J Epidemiol* dyab007 (2021) doi:10.1093/ije/dyab007.
14
15 24. Edwards, R. D. The cost of uncertain life span. *J Popul Econ* **26**, 1485–1522 (2013).
16
17 25. Levin, A. T. *et al.* Assessing the age specificity of infection fatality rates for COVID-19:
18 systematic review, meta-analysis, and public policy implications. *Eur J Epidemiol* **35**,
19 1123–1138 (2020).
20
21 26. Miller, S., Wherry, L. R. & Mazumder, B. Estimated Mortality Increases During The
22 COVID-19 Pandemic By Socioeconomic Status, Race, And Ethnicity: Study examines
23 COVID-19 mortality by socioeconomic status, race, and ethnicity. *Health Affairs* **40**,
24 1252–1260 (2021).
25
26 27. Sanchez-Romero, M., Lee, R. D. & Prskawetz, A. Redistributive effects of different
27 pension systems when longevity varies by socioeconomic status. *The Journal of the*
28 *Economics of Ageing* **17**, 100259 (2020).
29
30 28. Auerbach, A. J. *et al.* How the Growing Gap in Life Expectancy May Affect Retirement
31 Benefits and Reforms. *Geneva Pap Risk Insur Issues Pract* **42**, 475–499 (2017).
32
33 29. Ward, Z. J. *et al.* Estimating the impact of the COVID-19 pandemic on diagnosis and
34 survival of five cancers in Chile from 2020 to 2030: a simulation-based analysis. *The*
35 *Lancet Oncology* **0**, (2021).
36
37 30. Bambra, C., Riordan, R., Ford, J. & Matthews, F. The COVID-19 pandemic and health
38 inequalities. *J Epidemiol Community Health* **74**, 964–968 (2020).
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 **Figure legends:**
4
5

6
7 **Figure 1**
8

9 Life expectancy at birth by sex and condition of Urban and Non-urban
10 in Chile. Notes: Solid lines correspond to estimates based on the
11 entire population on each group, with bands indicating 95% credible
12 regions.
13
14
15
16

17
18
19 **Figure 2**
20

21 Probabiltiy of not surviving to 65 years by sex and condition of
22 Urban and Non-urban in Chile. Notes: Solid lines correspond to
23 estimates based on the entire population on each group, with bands
24 indicating 95% credible regions.
25
26
27
28
29

30
31
32 **Figure 3**
33

34 Relative yearly changes in Gini with respect to previous years
35 (starting 2002) for life expectancy at birth (A), average years
36 lived between 20 and 65 (B) and life expectancy at 65.
37
38
39
40

41
42 **Figure 4**
43

44 Changes in inequality of mortality in 2020 with respect to recent
45 history were stronger in younger age groups. A Comparison between
46 2015-2019 and 2020 of the average years lived between 20 and 65, for
47 males and females, as a function of poverty. B same as in A, but
48 with life expectancy at 65.
49
50
51
52
53
54
55
56
57
58
59
60

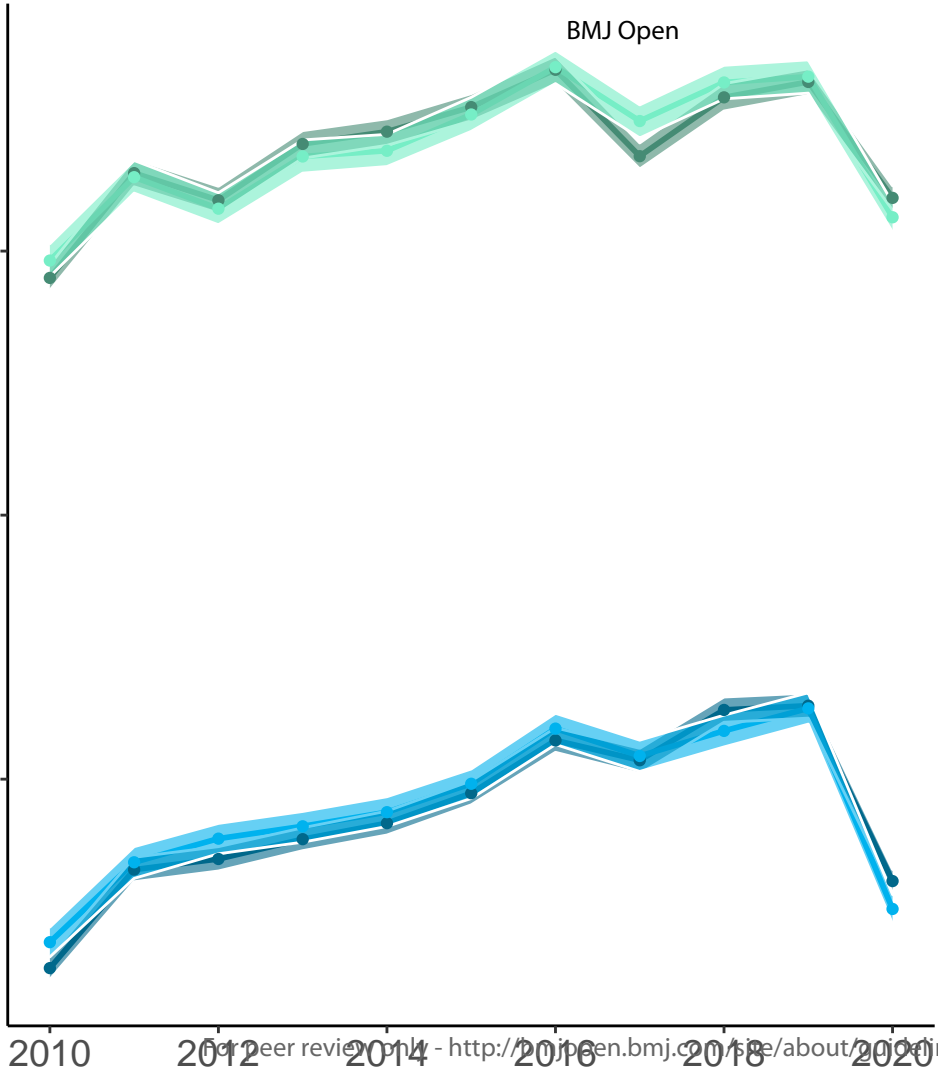
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For peer review only

BMJ Open

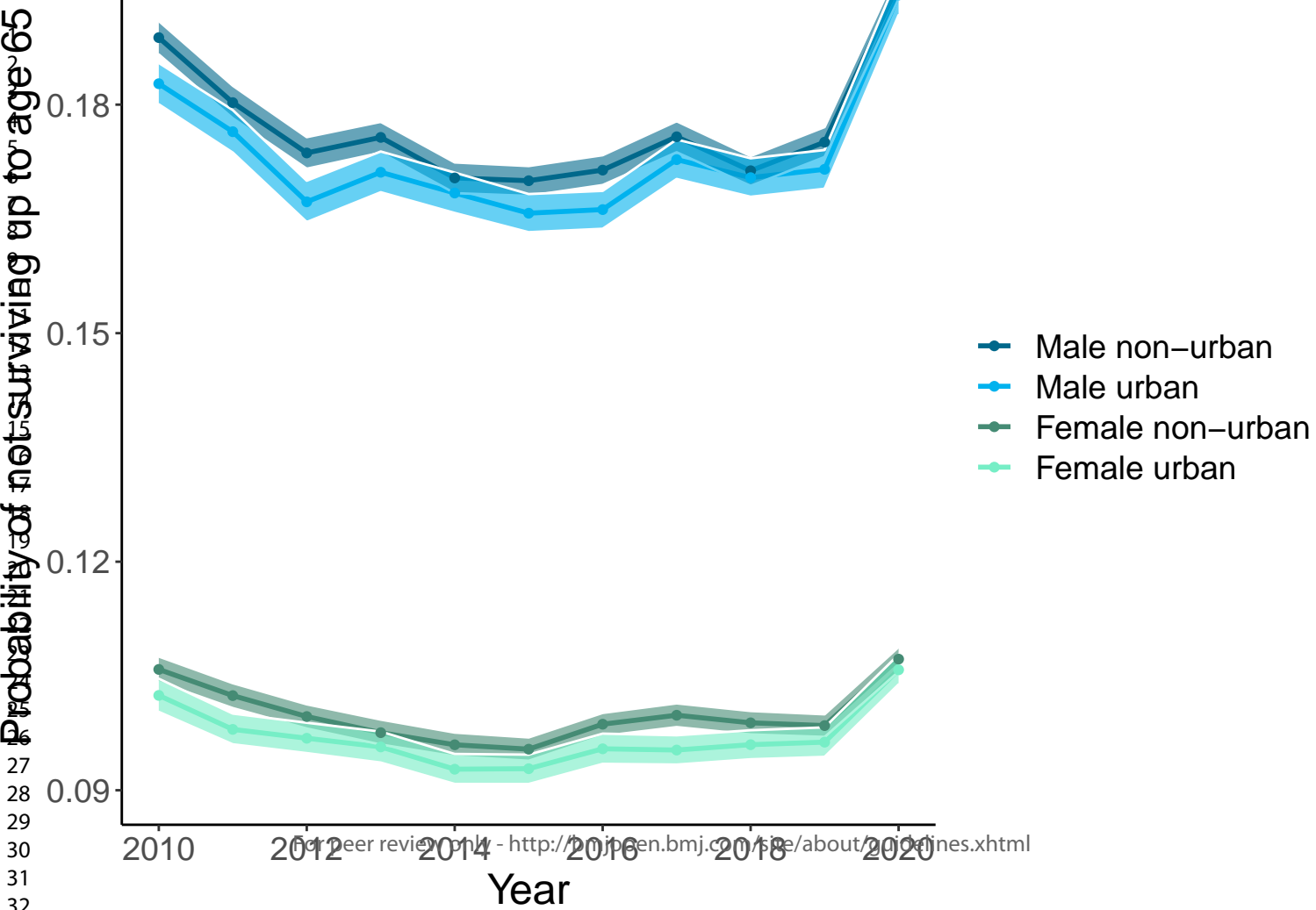
1
2
3
4
5
21
22
23
24
25
26
27
28
29
30
31
32

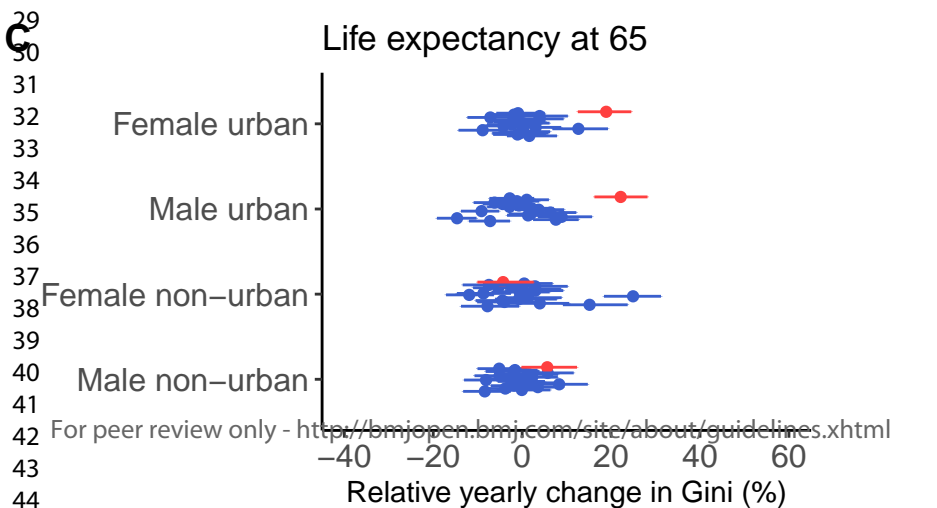
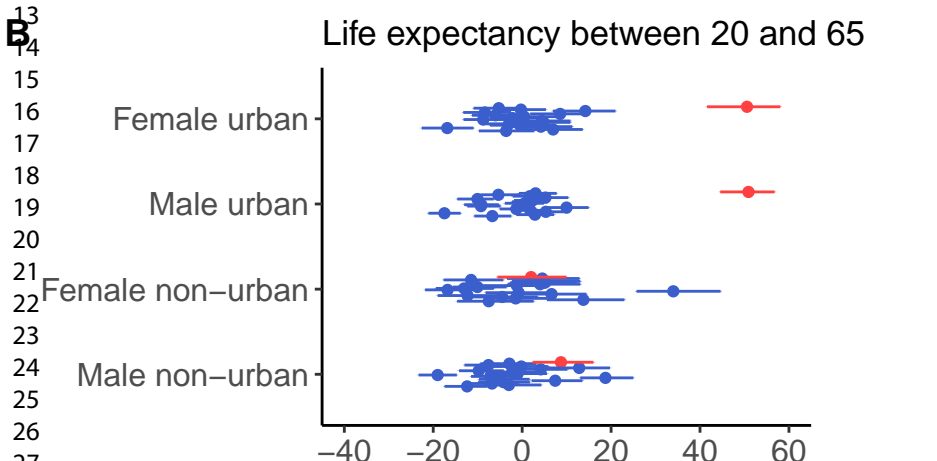
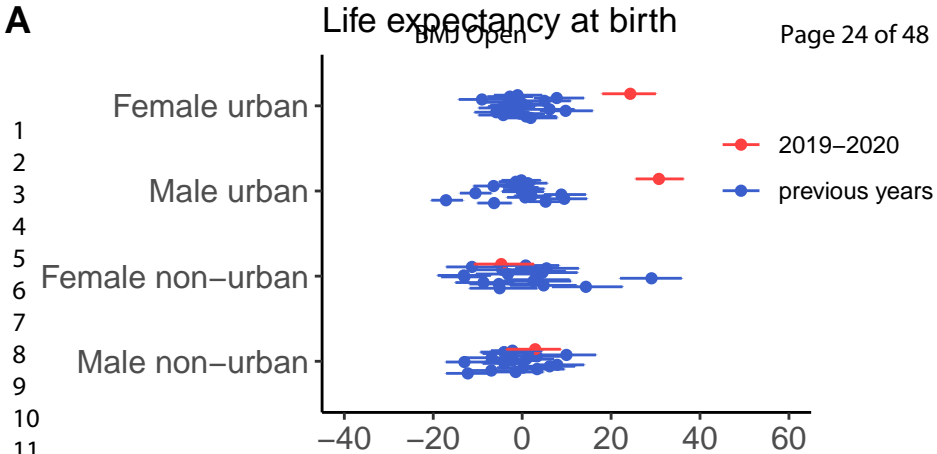
Life expectancy at birth



- Male non-urban
- Male urban
- Female non-urban
- Female urban

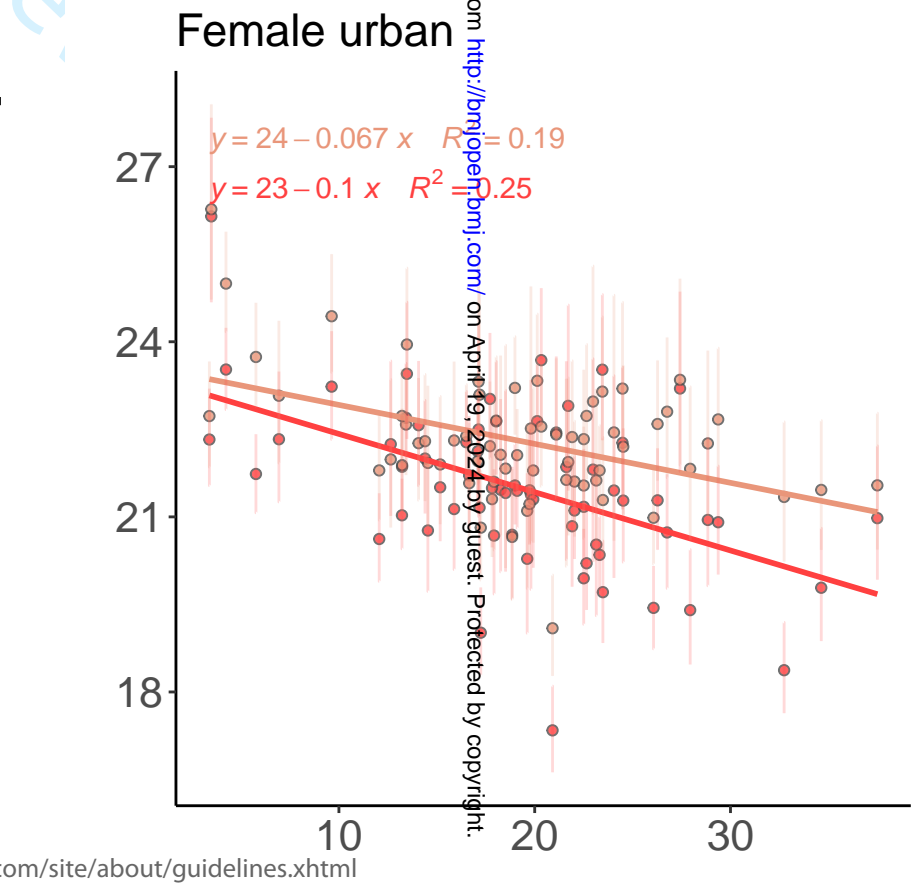
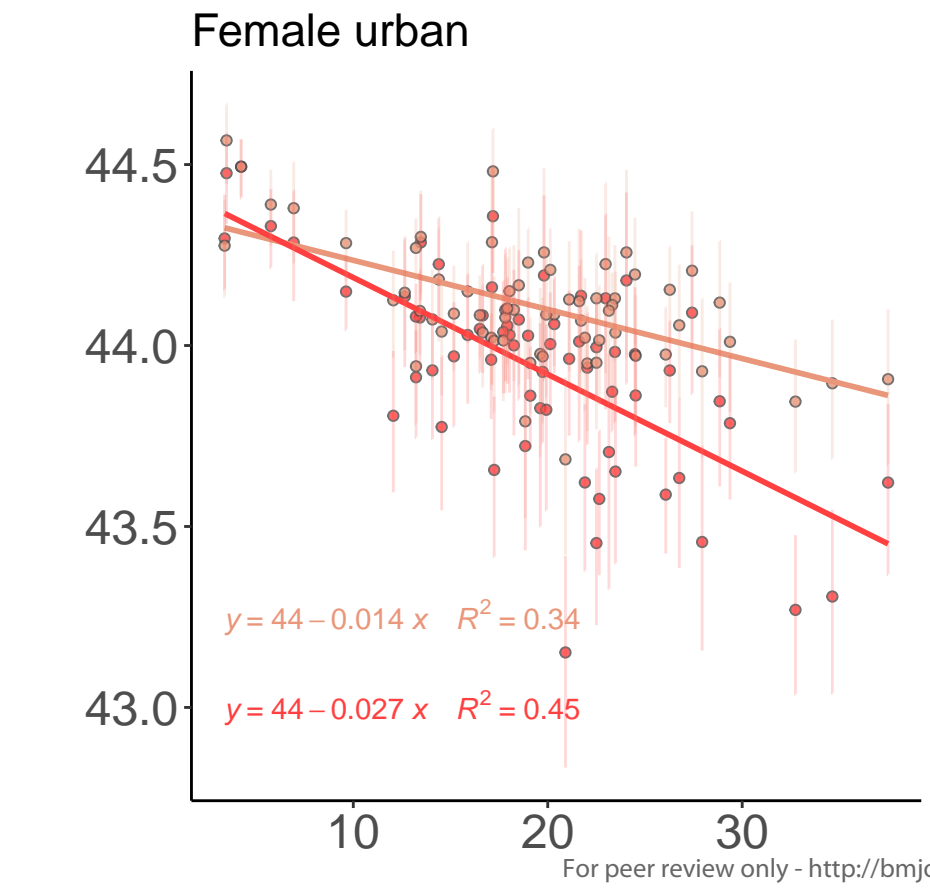
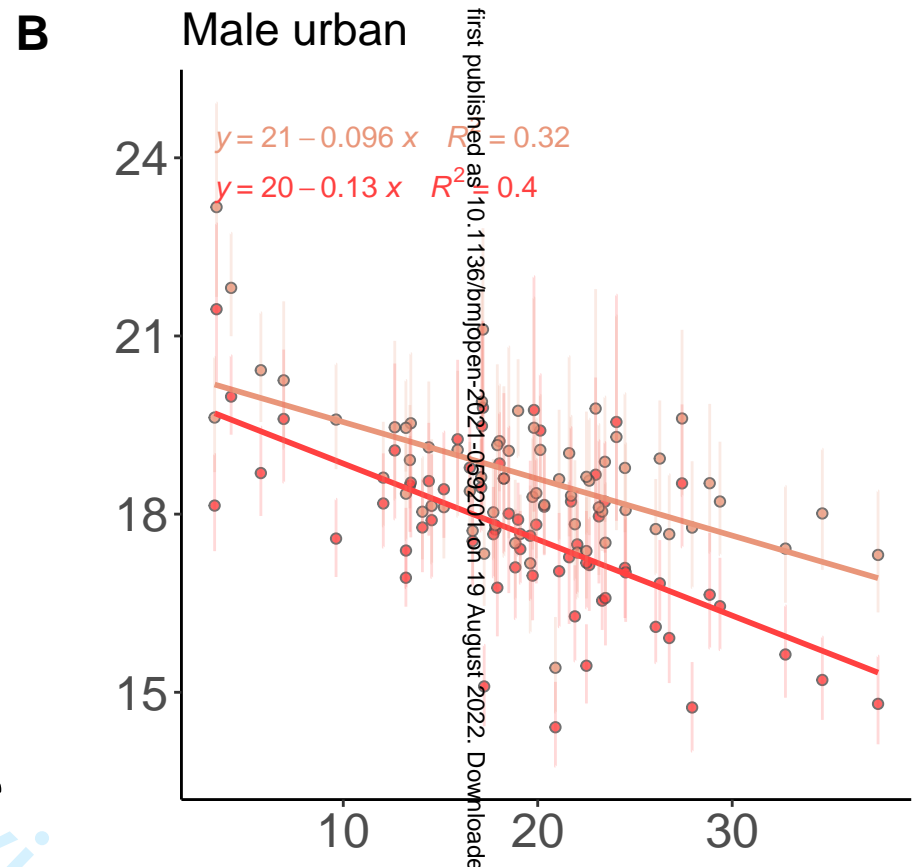
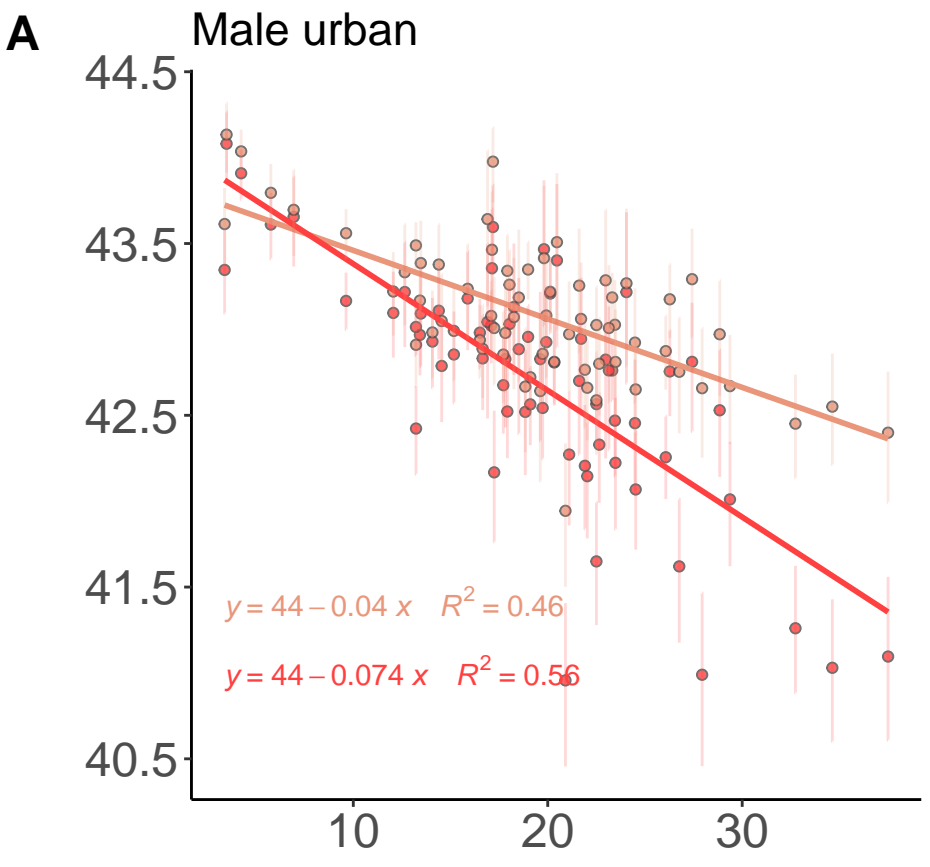
Year





2015–2019 2020

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



Life expectancy at 65

Poverty (%)

BMJ Open: first published as 10.1136/bmjopen-2021-029201 on 19 August 2022. Downloaded from <http://bmjopen.bmj.com/> on April 19, 2024 by guest. Protected by copyright.

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

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 were 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.

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

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.

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. Berdegúe, 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].).

		Urban	Rural	Excluded	Total
	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
Region	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.

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, 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
Valparaíso	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
O'Higgins	Talca, Curico, Constitucion, Maule, San Clemente, Cauquenes, Molina, Sagrada Familia, Teno, Linares, Colbun, Longavi, Parral, Retiro, San Javier, Villa Alegre, Yervas Buenas
Maule	Curepto, Empedrado, Pelarco, Penciahue, 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, 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
Metropolitana	Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado, Penaflo, Pirque, San Jose de Maipo, Colina, Lampa, Tiltill, 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.

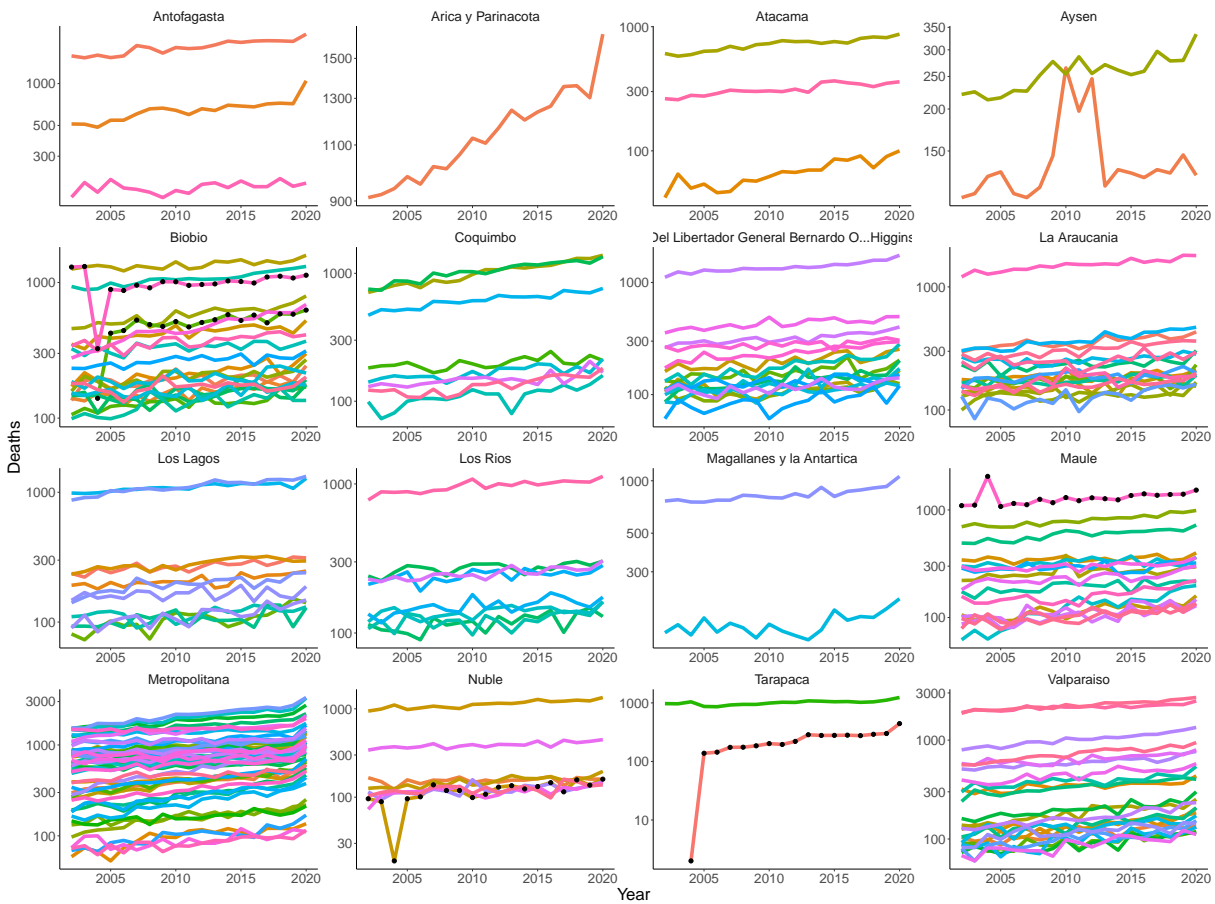


Figure 1: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring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

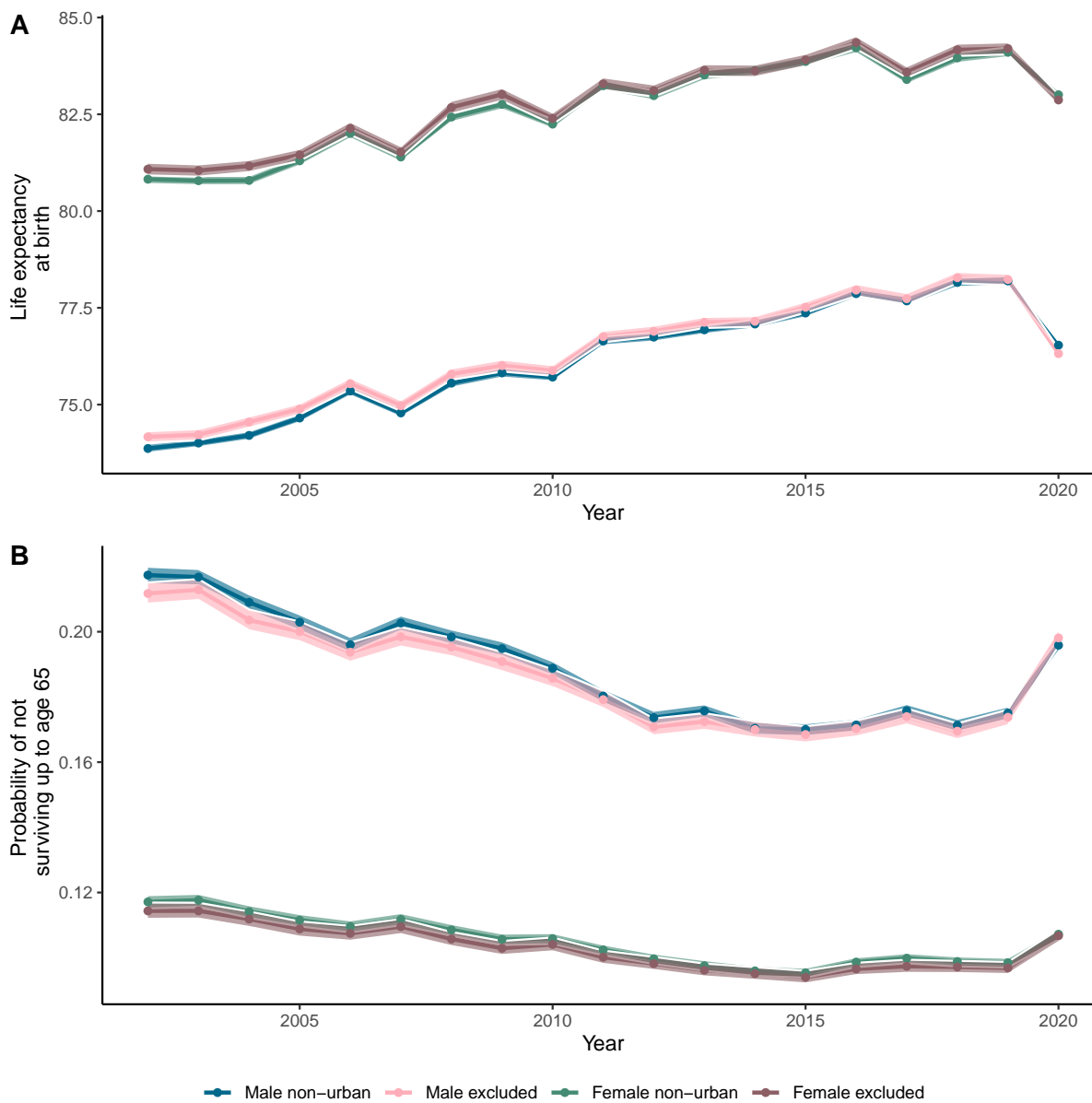


Figure 2: **A**. Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B**. Same as **A**, but with likelihood of dying before reaching 65.

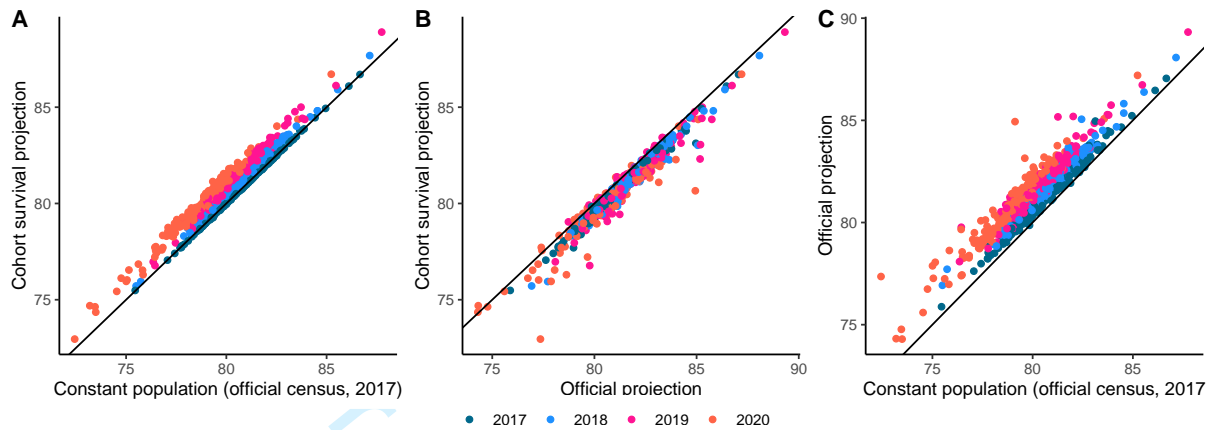


Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival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

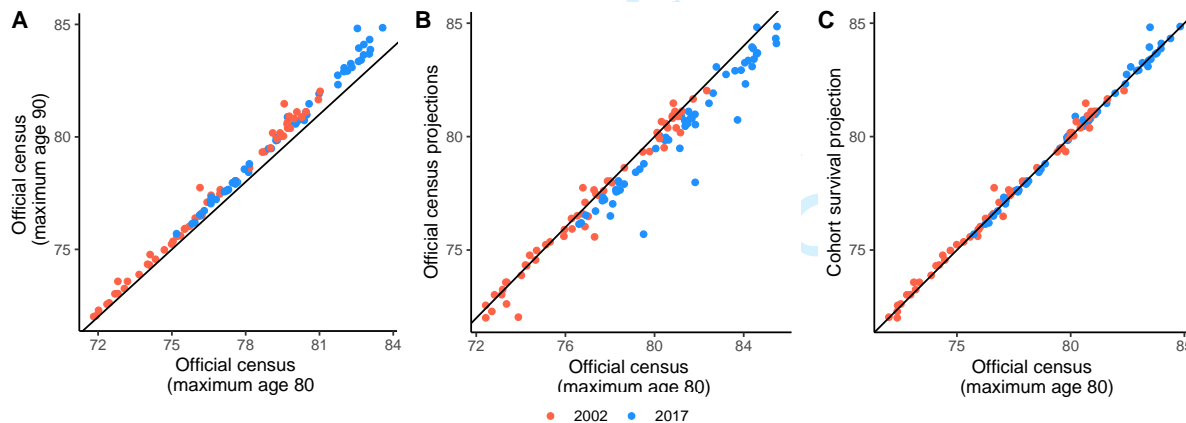


Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with 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.

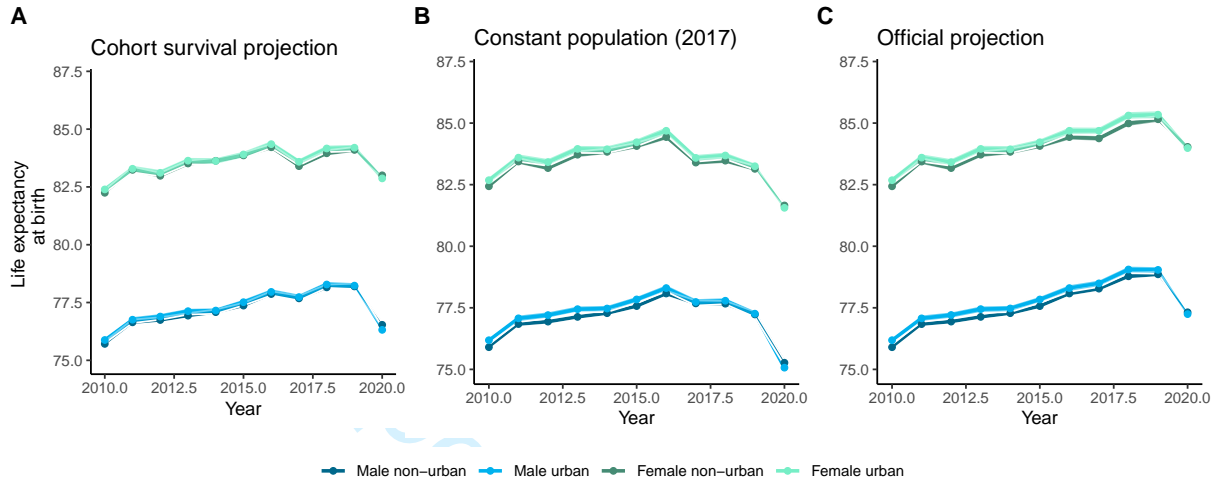


Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with A.

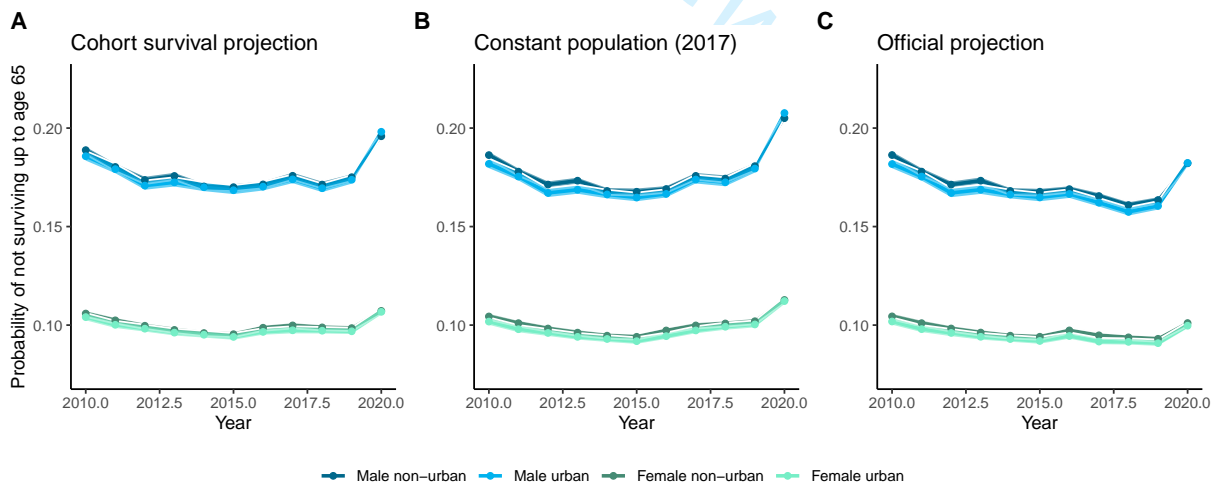


Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with A.

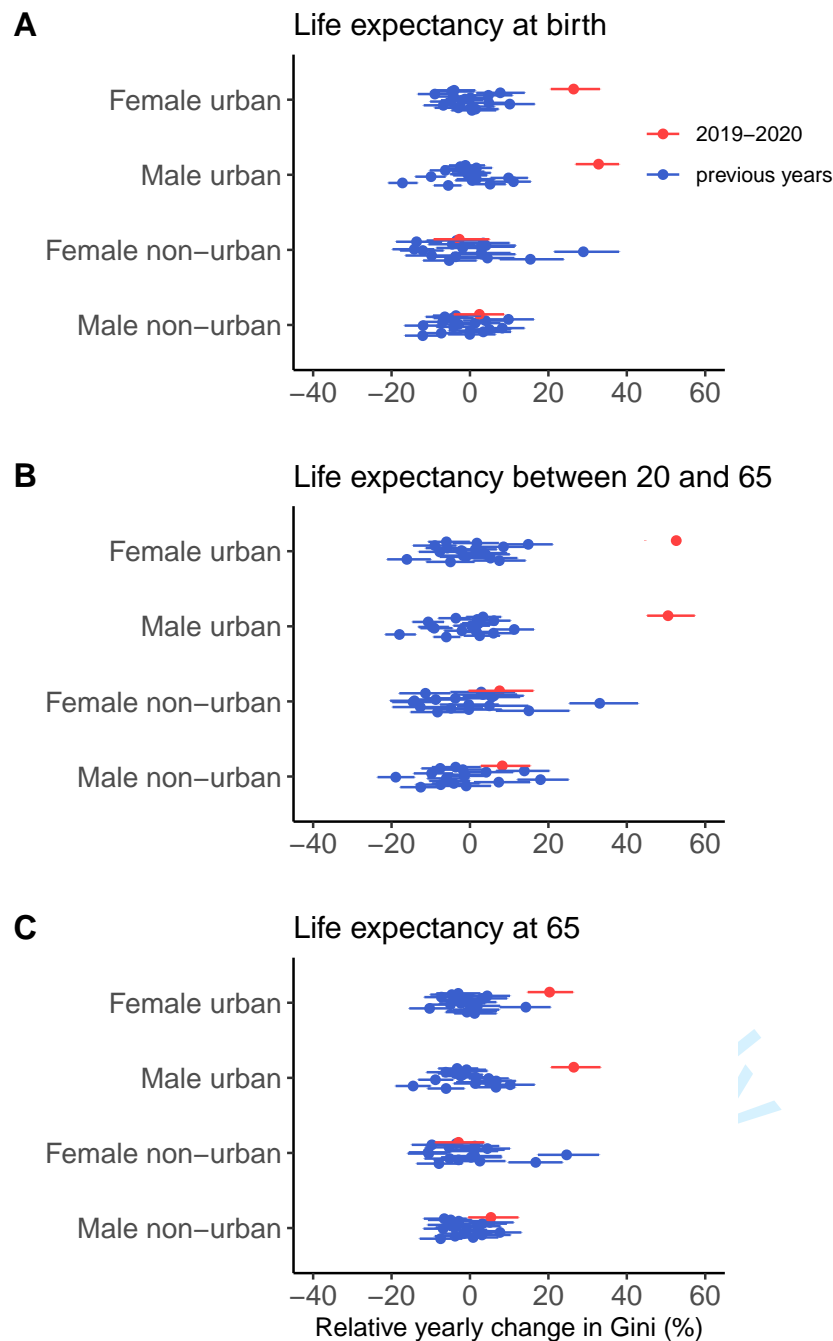


Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

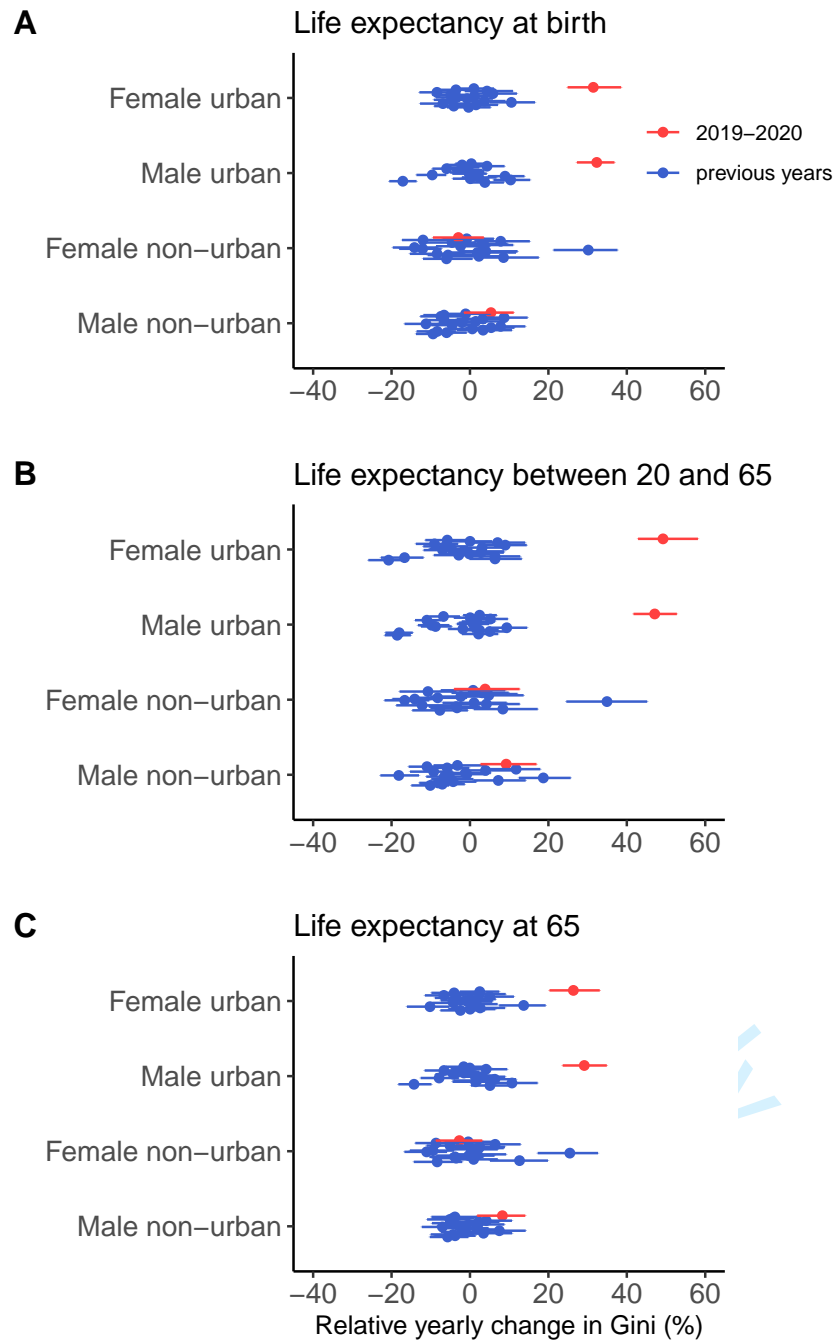


Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

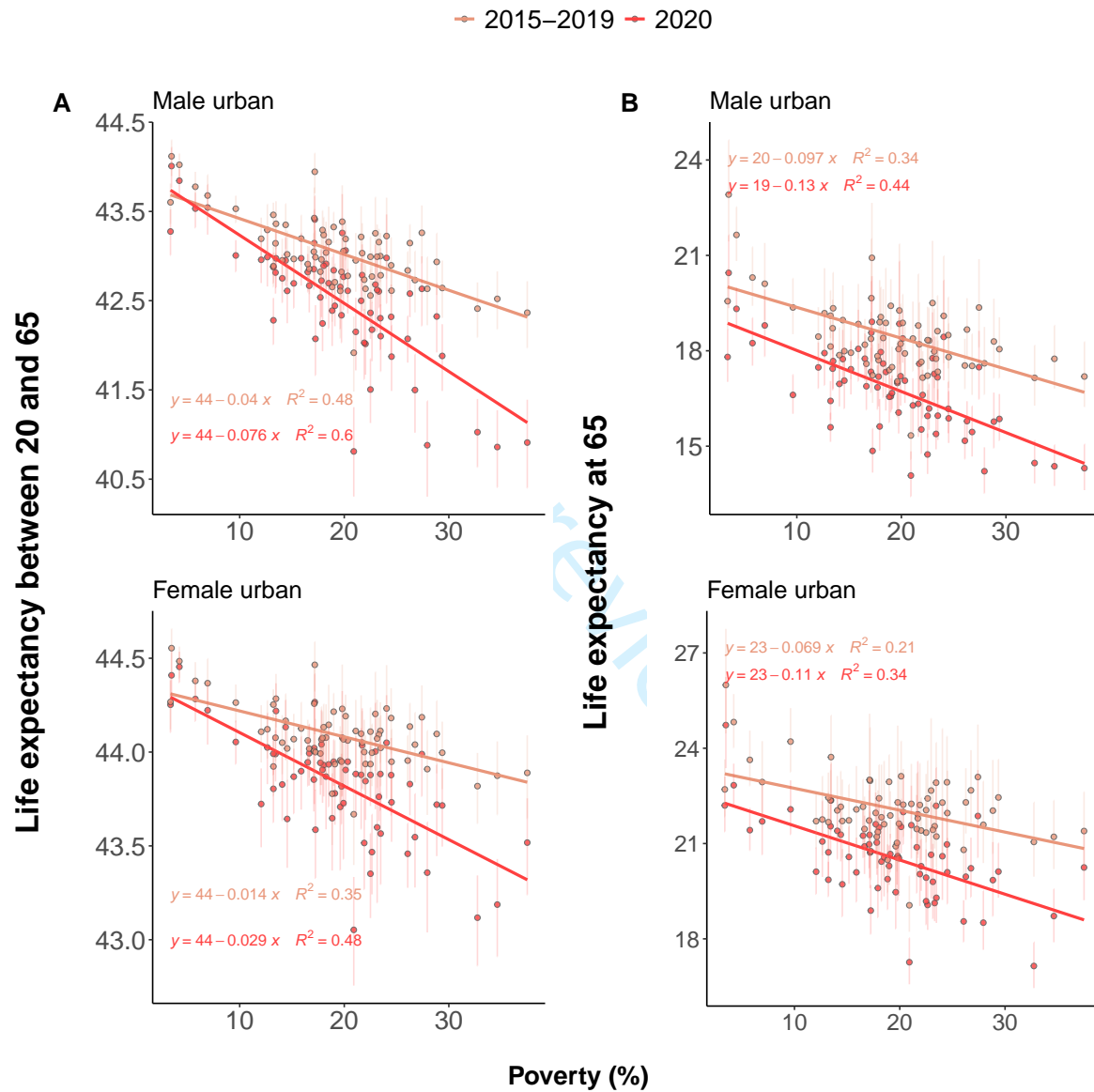


Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019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

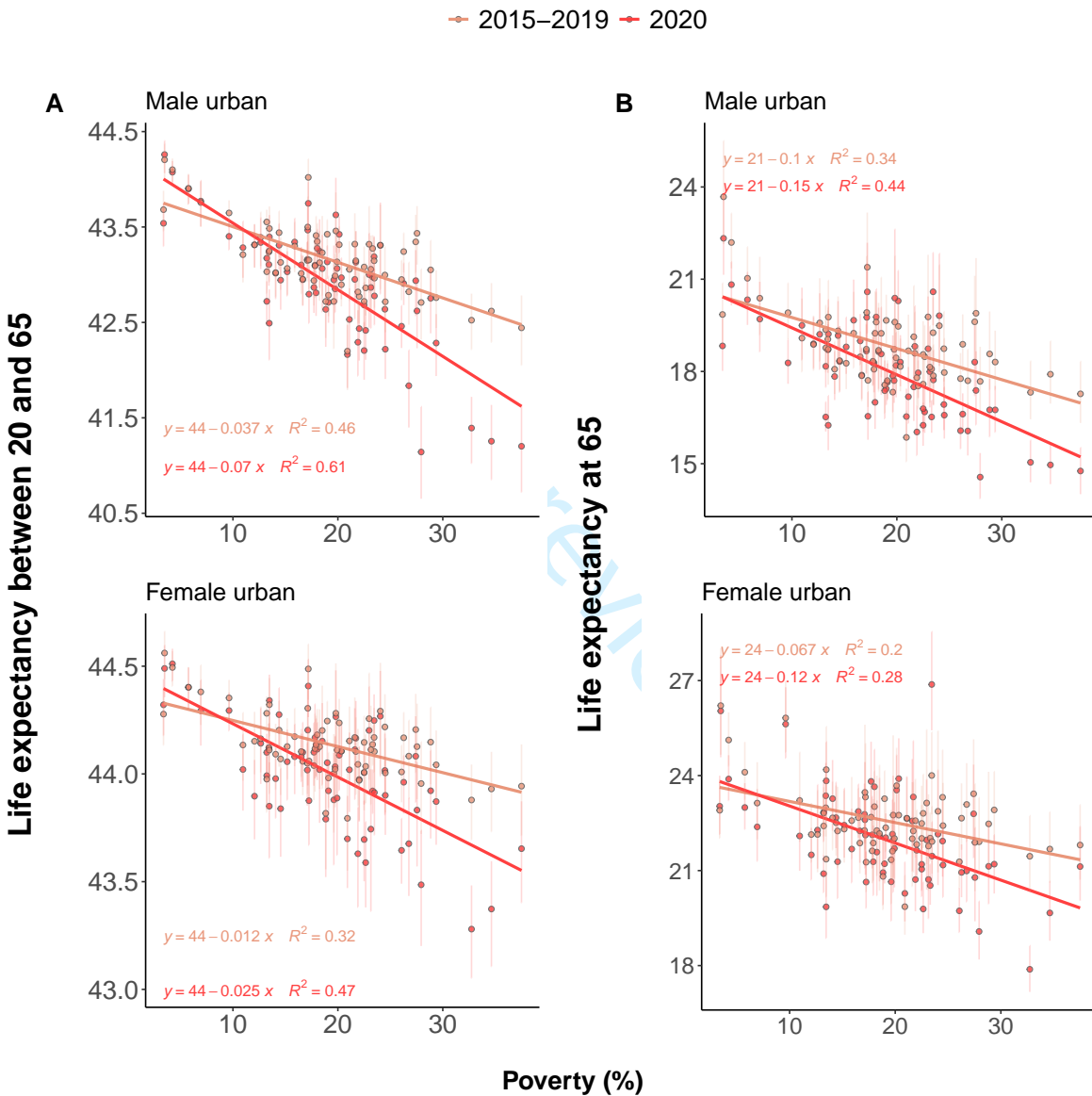


Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

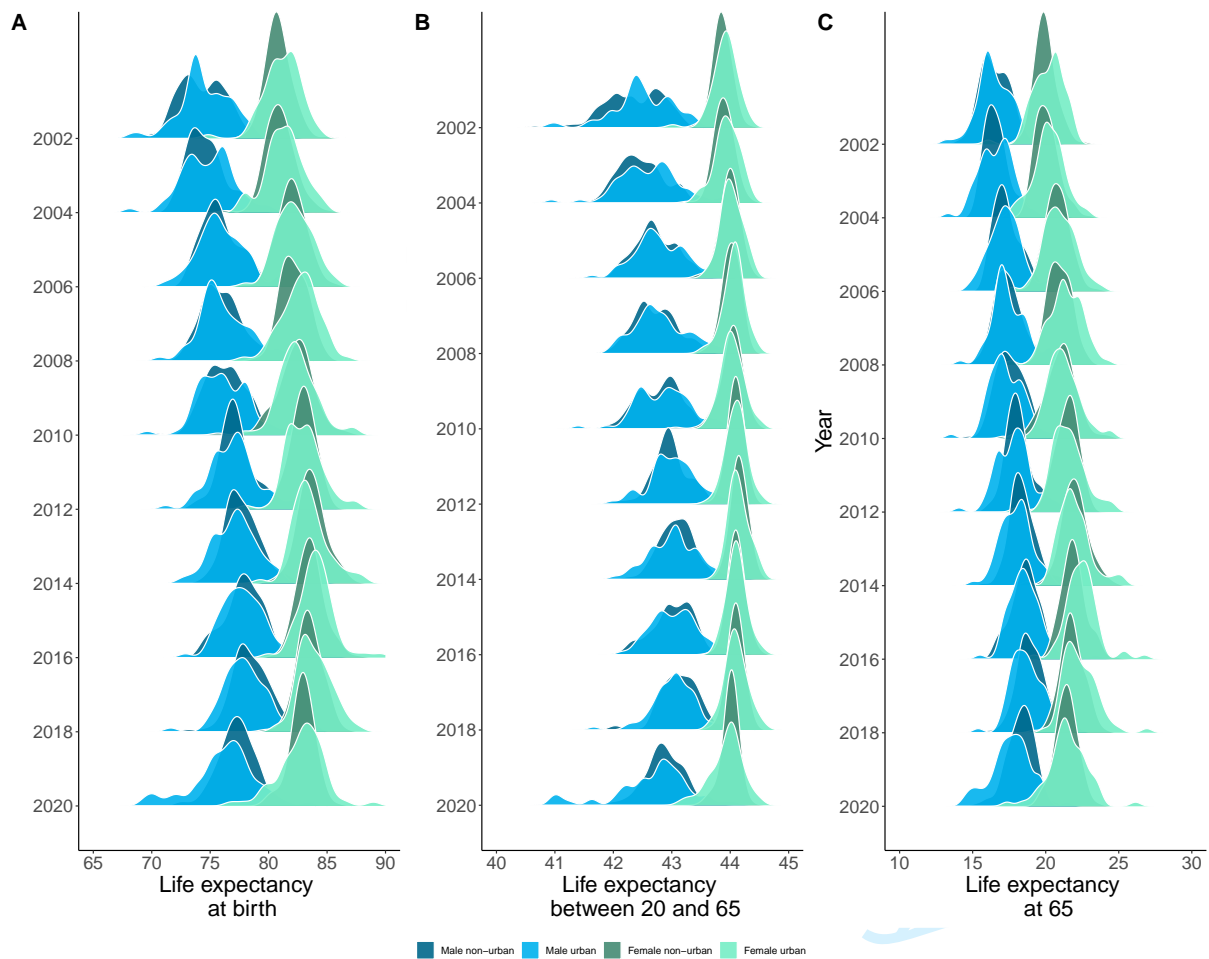


Figure 11: Histograms of life expectancies over time, for male/female and urban/non-urban settings. These histograms are made by taking each combination of gender as municipality as a sample. We note that a left tail appears during 2020 for urban municipalities

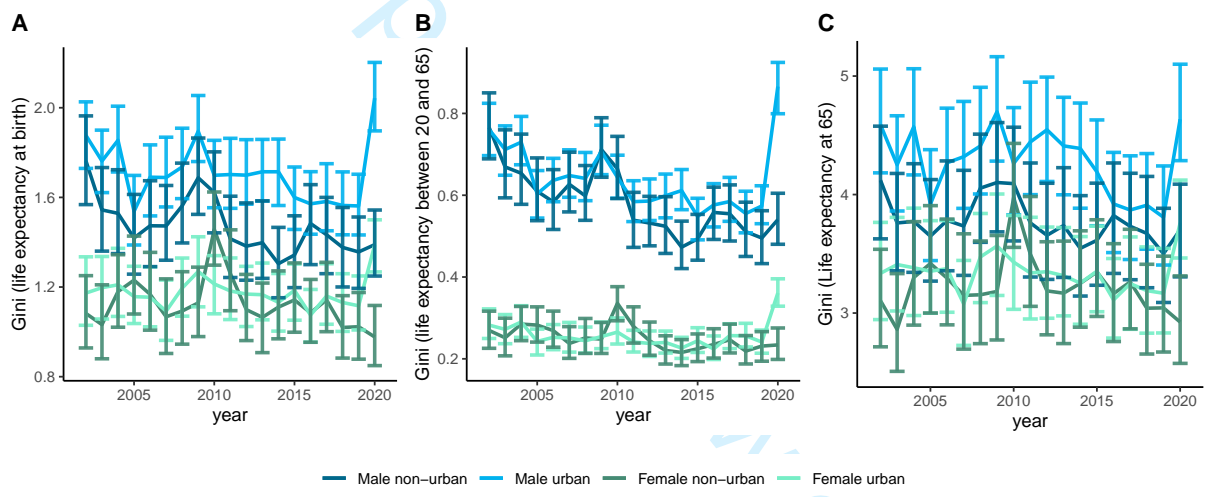


Figure 12: Time evolution of Gini. This plot supplements Exhibit 3, where only year-to-year differences are shown. Bars represent 95% credible intervals.

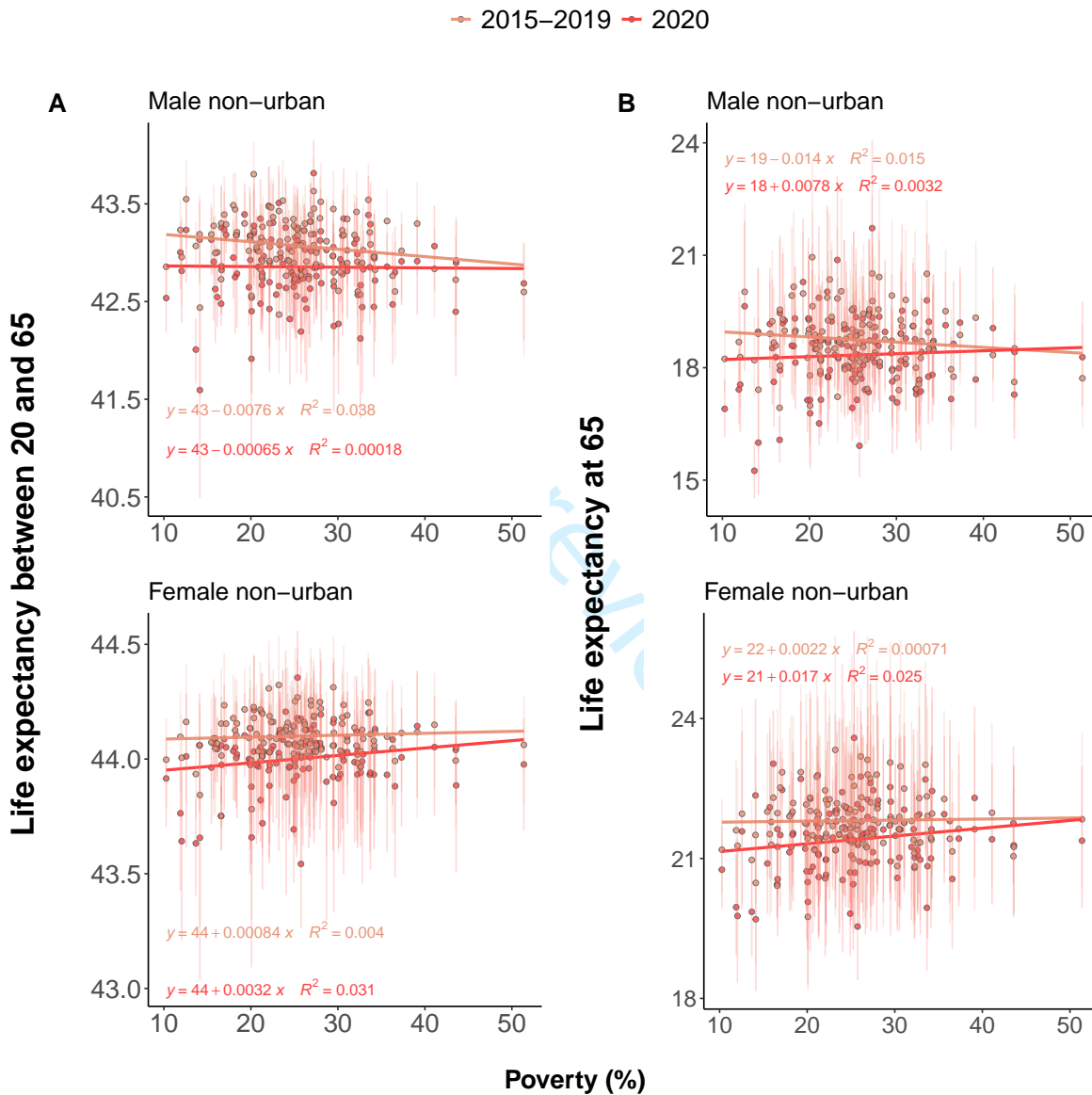


Figure 13: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

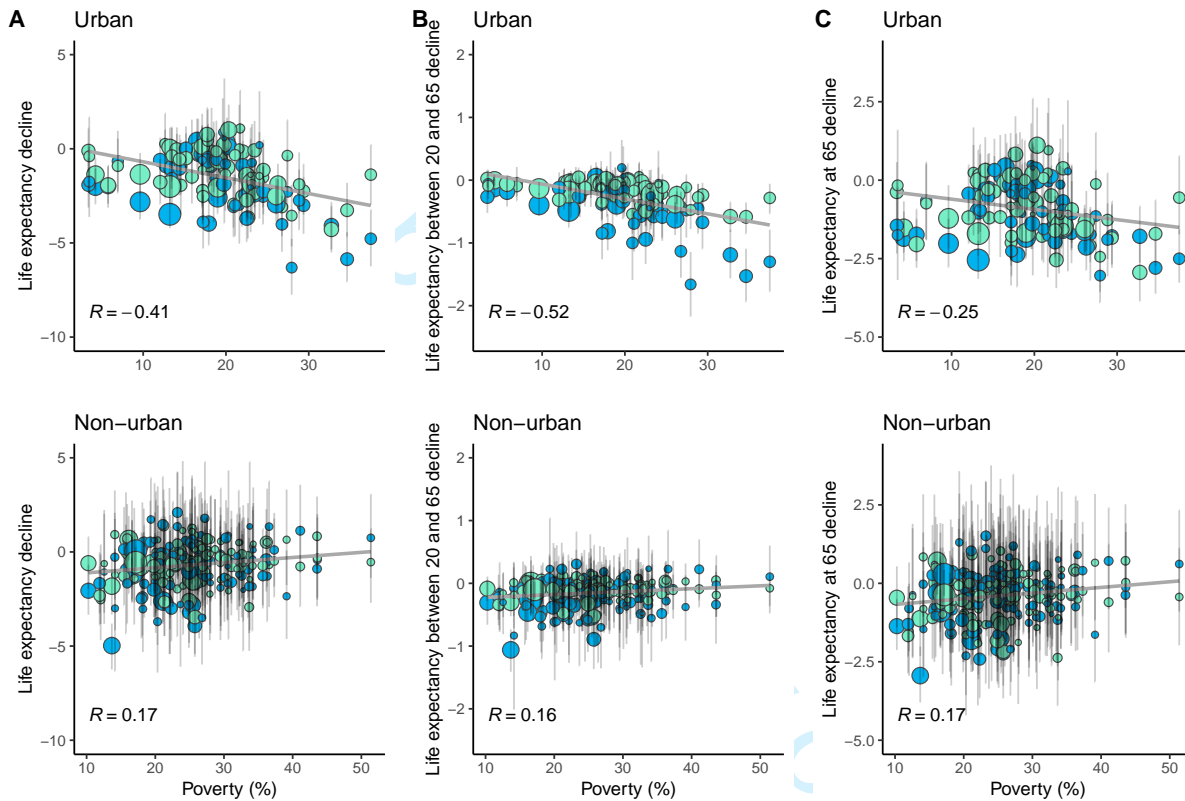
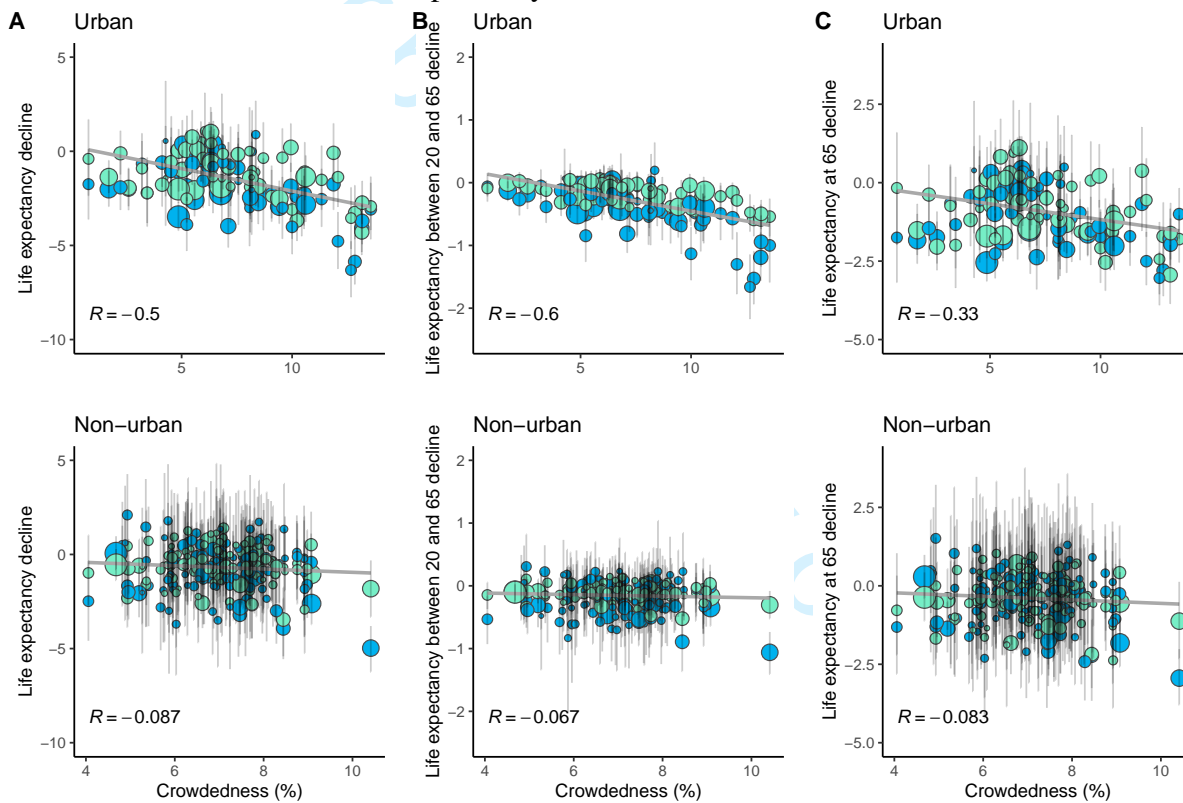


Figure 14: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and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



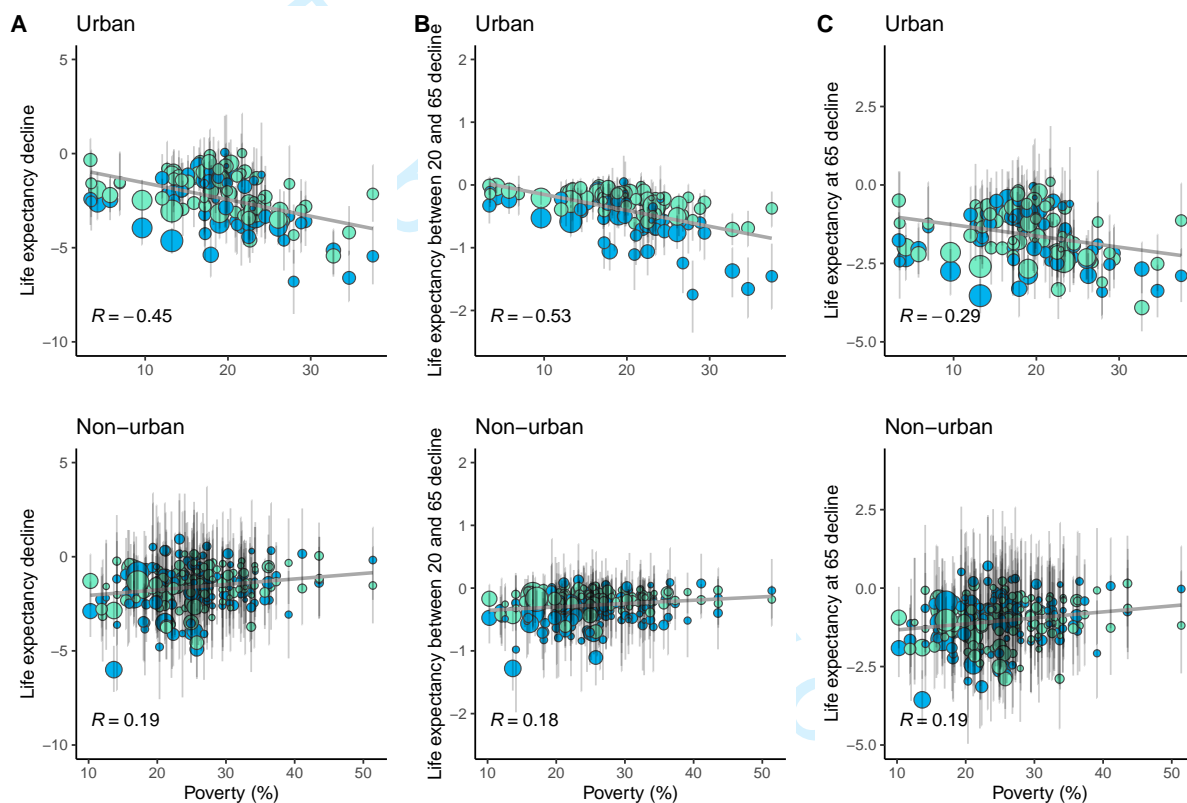


Figure 16: Same as 14 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

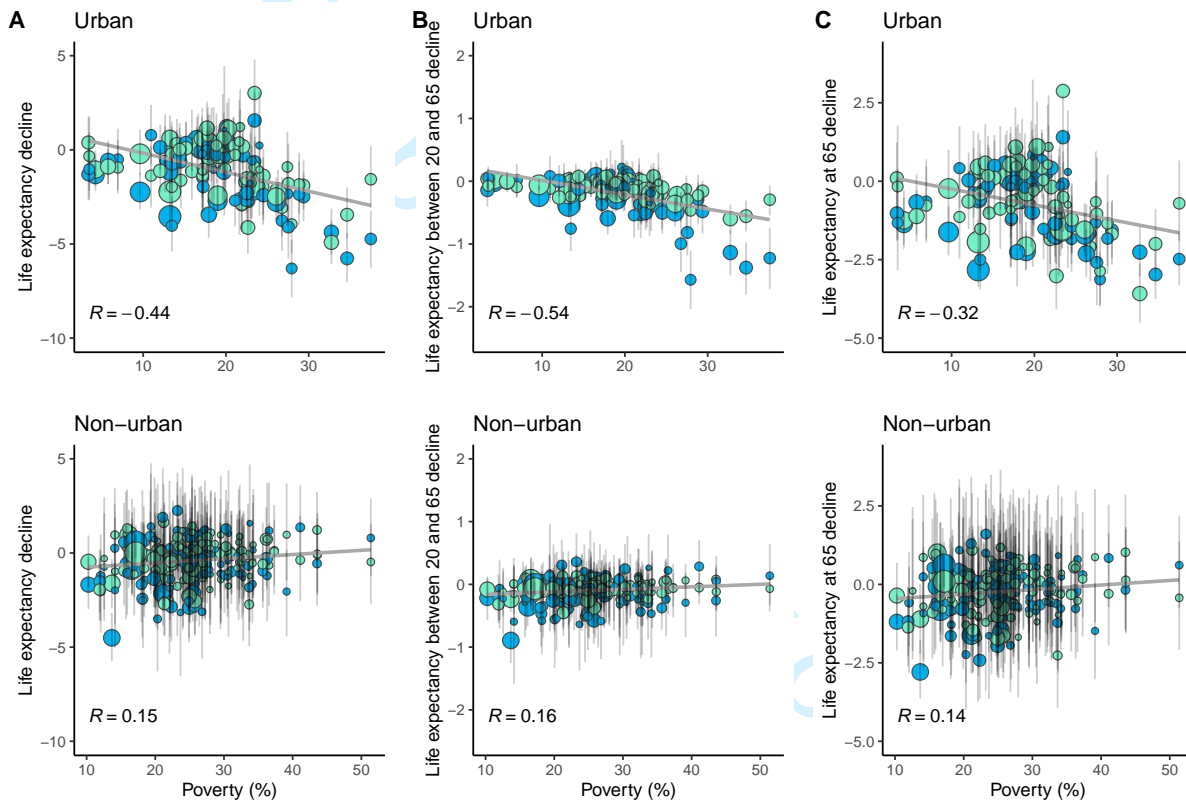


Figure 17: Same as 14 but with population estimates given by official projections.

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

1				
2	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
3			(b) Report category boundaries when continuous variables were categorized	NA
4			(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
5				
6	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-11
7				
8	Discussion			
9	Key results	18	Summarise key results with reference to study objectives	9-11
10	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
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
12	Generalisability	21	Discuss the generalisability (external validity) of the study results	9-11
13				
14	Other information			
15	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
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				

*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.

BMJ Open

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

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-059201.R1
Article Type:	Original research
Date Submitted by the Author:	11-Apr-2022
Complete List of Authors:	Mena, Gonzalo ; Oxford University, Statistics Aburto, José Manuel; University of Oxford, Leverhulme Centre for Demographic Science
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Health policy, Infectious diseases, Public health
Keywords:	COVID-19, Demography < TROPICAL MEDICINE, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

1
2
3 **Title:** The unequal impact of the COVID-19 pandemic in 2020 on life
4 expectancy across urban areas in Chile: A cross-sectional demographic
5 study.
6
7
8
9

10
11 **Authors:** Gonzalo E. Mena^{1,*}, José Manuel Aburto^{2,3}
12
13

14
15 **Affiliations:**
16

17
18
19 ¹Department of Statistics, University of Oxford; Oxford, UK (Email:
20 gonzalo.mena@stats.ox.ac.uk)
21
22

23
24
25 ²Leverhulme Centre for Demographic Science, Department of Sociology
26 and Nuffield College, University of Oxford; Oxford, UK (Email: jose-
27 manuel.aburto@sociology.ox.ac.uk)
28
29
30

31
32
33 ³Interdisciplinary Centre on Population Dynamics, University of
34 Southern Denmark; Odense 5000, Denmark.
35
36
37

38
39
40 *Corresponding author.
41
42
43
44
45

46 **Word count (main text, references):** 3229
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5 **Abstract (205 words):**
6

7 **Objectives:** To quantify the impact of the COVID-19 pandemic on life
8 expectancy in Chile categorized by rural and urban, and to correlate
9 life expectancy changes with socioeconomic factors at the municipal
10 level.
11
12
13
14

15 **Design:** Retrospective cross-sectional demographic analysis using
16 aggregated data.
17
18

19 **Setting:** Vital and demographic statistics from the national
20 institute of statistics and department of vital statistics of
21 ministry of health.
22
23
24
25

26 **Participants:** Aggregated national all-cause death data stratified by
27 year during the 2000-2020 period, sex, and municipality.
28
29

30 **Main Outcome measures:** Stratified mortality rates using a Bayesian
31 methodology. With this, we assessed the unequal impact of the
32 pandemic in 2020 on life expectancy across Chilean municipalities
33 for men and women and analyzed previous mortality trends since
34 2010.
35
36
37
38
39

40 **Results:** Life expectancy declined for both men and women in
41 2020. Urban areas were the most affected, with males losing
42 1.89 years and females 1.33 years in 2020. The strength of the
43 decline in life expectancy correlated positively with indicators of
44 social deprivation and poverty. Also, inequality in life
45 expectancy between municipalities increased, largely due to
46 excess mortality among the working-age population in socially
47 disadvantaged municipalities.
48
49
50
51
52
53

54 **Conclusions:** Not only do people in poorer areas live shorter
55 lives, they also have been substantially more affected by the
56 COVID-19 pandemic, leading to increased population health
57
58
59
60

1
2
3 inequalities. Quantifying the impact of the COVID-19 pandemic
4 on life expectancy provides a more comprehensive picture of
5 the toll.
6
7
8
9
10
11

12 **Keywords:** COVID-19, Latin America, Mortality, Life expectancy,
13 Health Inequalities
14
15
16
17

18 **Strengths and limitations**

19
20
21
22

- 23 • First study to analyze changes in life expectancy in
24 Chile with small-area resolution.
- 25 • We applied a hierarchical Bayesian methodology to estimate
26 life expectancies in the past 20 years.
- 27 • The study shows associations between life expectancy and
28 measures of social disadvantage in the context of the
29 pandemic.
- 30 • The study is limited by the small number of death counts
31 in some areas, which increases uncertainty around
32 estimates.
- 33 • Data quality may be a limitation for the study, which we
34 try to overcome with the Bayesian estimation of
35 mortality.
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

53 **Main Text**

54
55
56
57

58 **Introduction**

59
60

1
2
3 Most Latin American countries experienced substantial progress in
4 reducing premature mortality while increasing health standards over
5 the last century and into the first fifteen years of the twenty-
6 first century.^{1,2} But this progress has been reversed, as Latin
7 American countries have been severely affected by the COVID-19
8 pandemic.³ The region became the hotspot of the pandemic in June
9 2020 and by March 2022 more than one and a half million COVID-19
10 deaths have been reported.⁴
11
12
13
14
15
16
17
18
19
20
21
22
23

24 After decades of sustained improvements in life expectancy, leading
25 to levels comparable to low mortality countries, Chile experienced
26 losses in this indicator in 2020 due to increased excess mortality
27 during the COVID-19 pandemic (11 months for women and 1.3 years
28 among men).⁵ While national figures are important and informative,
29 they conceal heterogeneity at the subnational level, which can be
30 substantial. Emerging evidence from Latin American countries
31 suggests that the COVID-19 pandemic has disproportionately affected
32 disadvantaged groups with low socioeconomic status with large
33 regional variation.⁶⁻¹⁰ In the context of Santiago, Chile's capital,
34 the observed worse outcomes in more deprived areas were explained by
35 the combination of lower access to healthcare, poorer baseline
36 health status of individuals, higher exposure to Sars-COV2 because
37 of a reduced compliance with shelter-in-place orders (in turn,
38 reflecting the inability to work from home), and by an ineffective
39 epidemic surveillance system whose resources were predominantly
40 allocated to more affluent areas, hampering early containment
41 efforts.⁶
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5 One key question is how the interplay of social and demographic
6 factors at a more granular geographic scale affected life expectancy
7 during the first year of the pandemic. Focusing on differences in
8 mortality by age, sex, social deprivation and urbanity, we aimed at
9 exploring two main hypotheses: 1) life expectancy has been affected
10 differently for females and males by urbanity status. Since COVID-19
11 first waves concentrated their impact on urban centers in Chile,⁶ we
12 expect that declines of life expectancy were larger in urban areas.
13 Also, since COVID-19 outcomes are typically worse among males at the
14 national level,^{11,12} we expect larger drops in life expectancy among
15 males in urban areas. 2) Larger life-expectancy losses were more
16 predominant in socially deprived areas. This hypothesis stems from
17 the known negative correlation between poverty and life expectancy.¹³
18 But because of the intricate relation between COVID-19 deaths by age
19 and social deprivation, it is not straightforward to determine
20 whether this correlation became stronger during the pandemic. In
21 support of this hypothesis, recent research in Chile's Capital
22 showed a strong negative correlation between excess deaths and
23 socioeconomic status, and that this correlation was particularly
24 stark among younger age-groups but eventually evened out for the
25 elderly.⁶ Since life expectancy more strongly weights mortality at
26 younger ages, it is likely that excess young-age mortality may have
27 increased inequality in life expectancy. Alternatively, since death
28 rates increased exponentially with age and losses in life expectancy
29 in low mortality countries have been attributed mostly to mortality
30 above age 60,⁵ it is likely that the pandemic in 2020 was such a
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 strong shock that excess mortality differentials decreased, leading
4
5 to reducing inequalities between municipalities.
6
7
8
9

10
11 This article contributes towards a more comprehensive understanding
12
13 of the COVID-19 pandemic's burden on population health by estimating
14
15 life expectancy across Chilean municipalities by sex using a
16
17 powerful Bayesian methodology.¹⁴ We contextualize our results with
18
19 past trends of progress and disparities in life expectancy, and
20
21 comment on the the relevance of acknowledging such persisting
22
23 disparities in the design of social security mechanisms. Our study
24
25 is a step towards explaining the varied impacts of the pandemic by
26
27 analyzing trends in life expectancy over age at a more granular
28
29 level and by correlating life expectancy losses with indicators of
30
31 poverty in Chile.
32
33
34
35
36
37

38 **Study Data and Methods**

39 **Data**

40
41
42
43
44
45
46 We used data on births and deaths by age, sex and municipality from
47
48 publicly available vital statistics.¹⁵ These data were complemented
49
50 with official population counts by age (single years of age from 0
51
52 to 89 and collapsed in 90+), sex and municipality from the 2002 and
53
54 2017 censuses available from the National Institute of Statistics
55
56 (INE).¹⁶ We also used official population projections between 2002
57
58 and 2020 centered at the 2017 census.¹⁷ Unlike censuses themselves,
59
60

1
2
3 these projections collapsed all ages greater than 80 in one single
4
5 group. We only observed minor changes in our estimates based on
6
7 whether the open ended interval started at 80 or 90, but we did
8
9 observe that life expectancy estimates based on 2017 projections
10
11 were substantially higher than the ones based on the 2017 census. We
12
13 explain this by a possible inadequacy of the official projection for
14
15 later years. Because of this reason, we considered two alternative
16
17 population estimates for 2017 onwards. The first one assumes that
18
19 population counts remain fixed for years 2018, 2019 and 2020. In the
20
21 second one, we projected forward the population using the cohort
22
23 component method¹⁸ with 2017 as baseline assuming zero migration. We
24
25 also used census data to classify municipalities as urban or non-
26
27 urban following,¹⁹ if the following two conditions hold: i)
28
29 population density greater than 70 people per square kilometer, and
30
31 ii) the proportion of people living in an urban environment is
32
33 greater than 88%. Chile is made up of 366 municipalities and
34
35 according to this criteria, 35% are qualified as urban, making up
36
37 for the 65% of the population (17539805, as per the 2017 Census).
38
39 See Supplementary Tables 1-3 for details. .Data on poverty and
40
41 crowdedness were taken from the CASEN survey by the Chilean Ministry
42
43 of Social Development and Family.²⁰ CASEN is the most comprehensive
44
45 official poverty survey available in Chile. For poverty, we used the
46
47 'multidimensional poverty' indicator. In CASEN, a household is
48
49 defined to suffer from multidimensional poverty if it accumulates
50
51 22.5% of deprivation according to a weighted score that takes into
52
53 fifteen items from income, access to healthcare, labor, social
54
55 security, housing and social cohesion. Likewise, a household is
56
57 considered crowded if there are 2,5 or more people per room.
58
59
60

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 methodology¹⁴ based on a hierarchical Bayesian model²¹ 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

1
2
3 From these, period life expectancy at birth, temporary life
4
5 expectancy between ages 20 and 65, and remaining life expectancy at
6
7 age 65 were obtained. Life expectancy at birth refers to the average
8
9 years a cohort of newborns is expected to live given the current
10
11 mortality conditions. Similarly, life expectancy at age 65 refers to
12
13 the average years individuals aged 65 are expected to live if they
14
15 were to experience the current mortality conditions throughout their
16
17 lives. Given the emerging evidence about how younger age groups
18
19 below age 65 have also been affected by the pandemic in the context
20
21 of Chile, we constructed a measure to capture average longevity over
22
23 working ages through temporary life expectancy. Temporary life
24
25 expectancy between ages 20 and 65 refers to the average years lived
26
27 between these ages given prevalent mortality conditions.²² For
28
29 example, if no one were to die between these ages, then the
30
31 temporary life expectancy would be the full 45 years. To complement
32
33 our analysis we also consider the probability of not reaching age 65
34
35 as an indicator of premature mortality.
36
37
38
39

40 **Measuring heterogeneity**

41
42 We leverage the availability of life expectancy estimates at the
43
44 municipality level to conceive a fictitious population where each
45
46 municipality is a sample. We quantify the heterogeneity of this
47
48 population through the Gini coefficient.²³ The Gini coefficient is a
49
50 standard indicator of inequality employed in social sciences. In the
51
52 context of this paper, the Gini coefficient expresses the degree of
53
54 inequality in life expectancy across municipalities. With our
55
56 methodology, we can seamlessly quantify temporal changes of the Gini
57
58
59
60

1
2
3 for different strata (male/female, urban/non-urban) and report
4
5 credible intervals.
6
7
8

9 **Patient and Public Involvement**

10
11 No patients were involved in this paper, all the analyses are based
12
13 on aggregated data.
14
15
16
17
18
19

20 **Results**

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

22
23
24
25
26
27
28 Men and women from both urban and non-urban areas experienced steady
29
30 increases in life expectancy at birth from 2010 to 2019. Women
31
32 showed higher life expectancy at birth than men in all groups. In
33
34 contrast, higher mortality during 2020 led to sharp decreases in
35
36 life expectancy at birth (Figure 1). Life expectancy among men in
37
38 urban and non-urban areas declined by 1.89 (1.68,2.09) and 1.66
39
40 (1.50,1.80) years, respectively. Among women, life expectancy losses
41
42 were 1.33 (1.11,1.55) and 1.10 (0.92,1.28) years, respectively. The
43
44 magnitude of the decline from 2019 to 2020 offset most gains in life
45
46 expectancy experienced in the last decade, especially in urban
47
48 areas. In fact, 68% of the municipalities analyzed ended up with
49
50 lower life expectancy than in 2015, and this number rose to 75% in
51
52 urban municipalities. In terms of individuals, 76% (non-urban) and
53
54 78% (urban) of the population lived in a municipality that faced a
55
56 decline in life expectancy compared to 2015.
57
58
59
60

1
2
3 Declines in the probability of surviving to age 65 (Figure 2)
4
5 between 2019 and 2020 indicate that changes in life expectancy
6
7 cannot be fully attributed to increased mortality in older age
8
9 groups only. While mortality above age 65 has been documented as one
10
11 of the main contributors to declines in life expectancy
12
13 internationally, substantial increases in mortality below age 65 are
14
15 apparent in our results, especially among men in urban areas.
16
17
18
19

20 ***Changes in disparities in life expectancy during the COVID-19***
21 ***pandemic in 2020***
22
23
24
25

26 Figure 3 shows the time evolution of the inequality in life
27
28 expectancies across municipalities, and shows the striking impact of
29
30 COVID-19 on this quantity. Inequality increased in urban areas from
31
32 2019 to 2020 with changes oscillating around 25%, a rate not seen in
33
34 the recent past. The magnitude of increase is much larger in men and
35
36 women's life expectancy between ages 20 and 65 from urban areas
37
38 (50.9% and 50.6% for men and women respectively). Contrarily, in
39
40 non-urban areas we do not observe changes deviating significantly
41
42 from usual year-to-year fluctuations. Altogether, these results
43
44 indicate not only that mortality during 2020 became more unequal,
45
46 but that this inequality was driven mostly by the younger age group.
47
48
49

50
51 Histograms in Figure 3 suggest that the abrupt increase in
52
53 inequality during 2020 can be attributed to heavier left tails of
54
55 the life expectancy distribution, indicating an increase in the
56
57 amount of municipalities with a much lower-than-average life
58
59 expectancy. To better understand the factors driving this spike in
60

1
2
3 inequality, we investigated how declines in life expectancy during
4 2020 correlated with social deprivation indicators including poverty
5 and crowdedness focusing only on mortality above age 20 across urban
6 areas. Figure 4 shows the negative association between poverty and
7 life expectancy between age 20 and 65 and life expectancy at age 65.
8 To underscore how the relationship changed in the course of 2020, we
9 stratified the results juxtaposing the previous five years (2015-19)
10 with 2019-20. Results show a strong historical negative correlation
11 between life expectancies in both age groups, sexes and poverty
12 levels. Males in the top poverty decile have a 4.39 expectancy lower
13 life expectancy than in the bottom decile. They also live on average
14 0.92 less years between 20 and 65, and 2.22 from 65 onwards. For
15 females, these numbers are 2.51, 0.31 and 1.55 years. During 2020,
16 the slope became more negative, suggesting that those municipalities
17 with higher levels of poverty experienced greater losses in life
18 expectancy. This dependency was stronger in the younger age group.
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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 ($p<0.001$).

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

1
2
3 were largely driven by increased mortality in working ages at higher
4 levels of poverty. A potential explanation is that the working age
5 population's availability to work from home and be less exposed to
6 heightened risk of COVID-19 and its consequences varies across
7 poverty levels. Deprived populations in Chile's capital experienced
8 higher fatality rates as a consequence of worse baseline individual
9 health status and to an overwhelmed healthcare system.⁶ Similarly,
10 evidence from the US suggests that those individuals with less
11 availability to work from home had higher death rates compared to
12 those that could afford working from home in 2020.²⁸
13
14
15
16
17
18
19
20
21
22
23
24
25

26 An open question is whether this sudden increase in inequality
27 amounts to a shock that will be followed by a recovery to pre-
28 pandemic levels, or whether these changes will persist in the long
29 term. Beyond the immediate increase in premature mortality, this is
30 relevant because failing to acknowledge inequalities in mortality
31 may compromise the progressiveness and actuarial fairness of social
32 security and public pension systems in the long term,^{29,30} which could
33 be translated into higher mortality in the future. Similarly, the
34 scars left by the pandemic, including a weak health system, may
35 increase mortality from multiple causes of death. For example,
36 postponed cancer treatments and failure to detect other chronic
37 degenerative diseases timely may lead to lower levels of life
38 expectancy in the long term than it was projected. This highlights
39 the need for accurate and timely data on other causes of death.
40 Future analysis should focus on analyzing the consequences of the
41 COVID-19 pandemic, including multiple causes of death and diseases
42 to study the direct impacts from COVID-19 mortality as well as the
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 indirect impacts through other pathways of diseases and conditions.³¹
4
5 Our research, in this sense, provides a first outlook by focusing on
6
7 all-cause mortality.
8
9

10
11 As shown by our results, the case of Chile underscores the dire
12
13 widening of an already large mortality gap between those living in
14
15 deprived conditions and those living with higher income during the
16
17 COVID-19 crisis. Evidence shows that the health consequences of
18
19 external shocks such a pandemic or an economic crisis are not spread
20
21 equally across social deprivation levels.³² The COVID-19 pandemic
22
23 reminds us of the ever-present risk of such events, whose cumulative
24
25 impact may partially explain the ever-existing gaps in mortality.
26
27 Therefore, the way that this crisis has exposed the vulnerabilities
28
29 of socially deprived populations is a call to challenge the
30
31 monolithic view of a country's demographics in the design of social
32
33 security systems. New strategies incorporating a public health
34
35 perspective that considers widening inequalities should be
36
37 implemented to minimize the impacts of the COVID-19 pandemic on the
38
39 health status of the Chilean population both immediately and in the
40
41 long term.
42
43
44
45

46 **Limitations**

47
48
49
50
51 This study had several limitations. First, while Chile's vital
52
53 registration is one of the most reliable in Latin America, there are
54
55 likely to be inaccuracies in mortality registration due to age
56
57 misreporting and coverage across municipalities, as well as
58
59 systematic age overstatement.³³ Delays in recording deaths may lead
60

1
2
3 to incompleteness issues especially in urban areas. Our results on
4 life expectancy declines and mortality inequalities may be
5 considered a lower bound because of these issues. The effect of
6 systematic age overstatement is likely to affect our results too.
7 However, there is no information on what the age pattern of
8 overstatement is during the pandemic. To mitigate these inaccuracies
9 and their effects on our life expectancy estimates, we used a
10 hierarchical Bayesian model that helped to retrieve a reasonable
11 mortality profile across regions. Another limitation is that because
12 of the low number of deaths observed in some municipalities, the
13 degree of uncertainty around the estimates was very high, not
14 allowing us to include them in our analysis with confidence. We
15 excluded municipalities by sex with less than 16,000 people (as per
16 the 2017 census), as we observed that life expectancy estimates were
17 unstable even with our adopted Bayesian methodology. However, we
18 grouped them together and reproduced all results to avoid systematic
19 exclusion. Results were consistent and are shown in Supplementary
20 Figure 2. Almost all of these were all non-urban municipalities.
21 Some other six municipalities were excluded for the 2004 year based
22 on a visual inspection of mortality trends that were clearly
23 indicative of coding errors in the mortality database (see
24 Supplementary Figure 1) during that year. Despite these limitations,
25 we used the most reliable data for Chile and state-of-the-art
26 methodologies to gauge mortality dynamics across Chile.
27 Additionally, our results are limited in that stratified population
28 counts are typically model-based estimates (except at census years),
29 and might be biased. We studied the effect of alternative population
30 estimates in final outcome measures, as described in the Supplement
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 (Figures 3-15). Finally, because of our observational study design,
4
5 we are only able to measure associations but not proper causal
6
7 effects of poverty in mortality.
8
9

10
11 **Acknowledgements:** We are grateful to Alberto Palloni for comments on
12
13 earlier versions of the manuscript, and to Monica Alexander and
14
15 Ameer Dharamshi for sharing their code related to reference 12.
16
17

18
19
20 **Funding:** This work was supported by the British Academy's Newton
21
22 International Fellowship (JMA) and a ROCKWOOL Foundation's grant on
23
24 excess deaths (JMA).
25
26

27
28 **Data availability statement:** *The data underlying this article are*
29
30 *available in The datasets were derived from sources in the public*
31
32 *domain: .*
33
34

35
36
37 **Author contributions:** GM, data curation, software, validation GM and
38
39 JMA formal analysis, investigation, conceptualisation, methodology,
40
41 project administration, resources, validation, visualisation,
42
43 writing (original draft), and writing (review & editing) JMA funding
44
45 acquisition, supervision.
46
47

48
49 **Ethics approval:** This research project does not require ethics
50
51 approval as it uses only macro data that are freely available
52
53 online.
54
55

56
57 **Conflict of interest:** None declared.
58
59
60

References

1. World Health Organization. *The World health report : 2000 : Health systems : improving performance*. (World Health Organization, 2000).
2. Alvarez, J.-A., Aburto, J. M. & Canudas-Romo, V. Latin American convergence and divergence towards the mortality profiles of developed countries. *Population Studies* **74**, 75–92 (2020).
3. Castanheira, H. C., Costa Monteiro da Silva, J. H., Del Popolo, F., Guiomar, B. & Saad, P. COVID-19 mortality. Evidence and scenarios. *Latin American and Caribbean Demographic Centre (CELADE)-Population Division of ECLAC, United Nations* (2021).
4. Sullivan, M. & Myer, P. Latin America and the Caribbean: Impact of COVID-19. <https://crsreports.congress.gov/product/details?prodcode=IF11581>.
5. Aburto, J. M. *et al.* Quantifying impacts of the COVID-19 pandemic through life-expectancy losses: a population-level study of 29 countries. *International Journal of Epidemiology* (2021) doi:10.1093/ije/dyab207.
6. Mena, G. E. *et al.* Socioeconomic status determines COVID-19 incidence and related mortality in Santiago, Chile. *Science* (2021) doi:10.1126/science.abg5298.
7. Millalen, P., Nahuelpan, H., Hofflinger, A. & Martinez, E. COVID-19 and Indigenous peoples in Chile: vulnerability to contagion and mortality. *AlterNative: An International Journal of Indigenous Peoples* **16**, 399–402 (2020).
8. Lima, E. E. C. *et al.* Investigating regional excess mortality during 2020 COVID-19 pandemic in selected Latin American countries. *Genus* **77**, 30 (2021).
9. Cifuentes, M. P., Rodriguez-Villamizar, L. A., Rojas-Botero, M. L., Alvarez-Moreno, C. A. & Fernández-Niño, J. A. Socioeconomic inequalities associated with mortality for COVID-19 in Colombia: a cohort nationwide study. *J Epidemiol Community Health* **75**, 610–615 (2021).
10. Castro, M. C. *et al.* Reduction in life expectancy in Brazil after COVID-19. *Nat Med* 1–7

- (2021) doi:10.1038/s41591-021-01437-z.
11. Schoeley, J. *et al.* Bounce backs amid continued losses: Life expectancy changes since COVID-19. 2022.02.23.22271380 (2022) doi:10.1101/2022.02.23.22271380.
 12. Aburto, J. M., Schöley, J., Kashnitsky, I. & Kashyap, R. Life expectancy declines in Russia during the COVID-19 pandemic in 2020. (2021) doi:10.31219/osf.io/7cuvy.
 13. Bilal, U. *et al.* Inequalities in life expectancy in six large Latin American cities from the SALURBAL study: an ecological analysis. *The Lancet Planetary Health* **3**, e503–e510 (2019).
 14. Alexander, M., Zagheni, E. & Barbieri, M. A Flexible Bayesian Model for Estimating Subnational Mortality. *Demography* **54**, 2025–2041 (2017).
 15. Departamento de Estadísticas Vitales. Departamento de Estadísticas e Información de Salud. <https://deis.minsal.cl/>.
 16. Instituto Nacional de Estadísticas de Chile. Instituto Nacional de Estadísticas de Chile. <https://redatam-ine.ine.cl/>.
 17. INE. Proyecciones de Población. *Default* <http://www.ine.cl/estadisticas/sociales/demografia-y-vitales/proyecciones-de-poblacion>.
 18. Preston, S. H., Heuveline, P. & Guillot, M. *Demography, Measuring and Modeling Population Processes*. (Wiley Blackwell, 2001).
 19. Berdegué, J., Jara, E., Modrego, F., Sanclemente, X. & Schejtman, A. *Ciudades rurales de Chile. Working papers* <https://ideas.repec.org/p/rms/wpaper/061.html> (2010).
 20. Ministerio de Desarrollo Social. Observatorio Social - Ministerio de Desarrollo Social y Familia. <http://observatorio.ministeriodesarrollosocial.gob.cl/encuesta-casen>.
 21. Gelman, A., Carlin, J. B., Stern, H. S. & Rubin, D. B. *Bayesian Data Analysis*. (Chapman and Hall/CRC, 1995). doi:10.1201/9780429258411.
 22. Arriaga, E. E. Measuring and Explaining the Change in Life Expectancies. *Demography* **21**, 83–96 (1984).
 23. Gini, C. Measurement of Inequality of Incomes. *The Economic Journal* **31**, 124–126 (1921).

- 1
2
3 24. Bilal, U., Alfaro, T. & Vives, A. COVID-19 and the worsening of health inequities in
4 Santiago, Chile. *Int J Epidemiol* dyab007 (2021) doi:10.1093/ije/dyab007.
5
6
7 25. Edwards, R. D. The cost of uncertain life span. *J Popul Econ* **26**, 1485–1522 (2013).
8
9 26. Levin, A. T. *et al.* Assessing the age specificity of infection fatality rates for COVID-19:
10 systematic review, meta-analysis, and public policy implications. *Eur J Epidemiol* **35**,
11 1123–1138 (2020).
12
13
14 27. Aburto, J. M. *et al.* Quantifying impacts of the COVID-19 pandemic through life
15 expectancy losses. *medRxiv* 2021.03.02.21252772 (2021)
16
17 doi:10.1101/2021.03.02.21252772.
18
19 28. Miller, S., Wherry, L. R. & Mazumder, B. Estimated Mortality Increases During The
20 COVID-19 Pandemic By Socioeconomic Status, Race, And Ethnicity: Study examines
21 COVID-19 mortality by socioeconomic status, race, and ethnicity. *Health Affairs* **40**,
22 1252–1260 (2021).
23
24 29. Sanchez-Romero, M., Lee, R. D. & Prskawetz, A. Redistributive effects of different
25 pension systems when longevity varies by socioeconomic status. *The Journal of the*
26 *Economics of Ageing* **17**, 100259 (2020).
27
28 30. Auerbach, A. J. *et al.* How the Growing Gap in Life Expectancy May Affect Retirement
29 Benefits and Reforms. *Geneva Pap Risk Insur Issues Pract* **42**, 475–499 (2017).
30
31 31. Ward, Z. J. *et al.* Estimating the impact of the COVID-19 pandemic on diagnosis and
32 survival of five cancers in Chile from 2020 to 2030: a simulation-based analysis. *The*
33 *Lancet Oncology* **0**, (2021).
34
35 32. Bambra, C., Riordan, R., Ford, J. & Matthews, F. The COVID-19 pandemic and health
36 inequalities. *J Epidemiol Community Health* **74**, 964–968 (2020).
37
38 33. Palloni, A., Beltrán-Sánchez, H. & Pinto, G. Estimation of older-adult mortality from
39 information distorted by systematic age misreporting. *Population Studies* **0**, 1–18 (2021).
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 **Figure legends:**
4
5

6
7 **Figure 1**
8

9 Life expectancy at birth by sex and condition of Urban and Non-urban
10 in Chile. Notes: Solid lines correspond to estimates based on the
11 entire population on each group, with bands indicating 95% credible
12 regions.
13
14
15
16

17
18
19
20 **Figure 2**
21

22 Probabiltiy of not surviving to 65 years by sex and condition of
23 Urban and Non-urban in Chile. Notes: Solid lines correspond to
24 estimates based on the entire population on each group, with bands
25 indicating 95% credible regions.
26
27
28
29

30
31
32 **Figure 3**
33

34 Time evolution (2002 to 2020 period) of the heterogeneity in life
35 expectancy at birth (left), between 20 and 65 years (center) and at
36 65 years (right). **A** histograms of life expectancies over time, for
37 male/female and urban/non-urban divisions. **B** Time evolution of Gini
38 of the corresponding histograms in **A**. **C** Relative yearly changes in
39 the Gini's with respect to previous years. Bars represent 95%
40 credible intervals in B and C.
41
42
43
44
45
46
47
48
49
50
51

52
53 **Figure 4**
54

55 Changes in inequality of mortality in 2020 with respect to recent
56 history were stronger in younger age groups. A Comparison between
57 2015-2019 and 2020 of the average years lived between 20 and 65, for
58
59
60

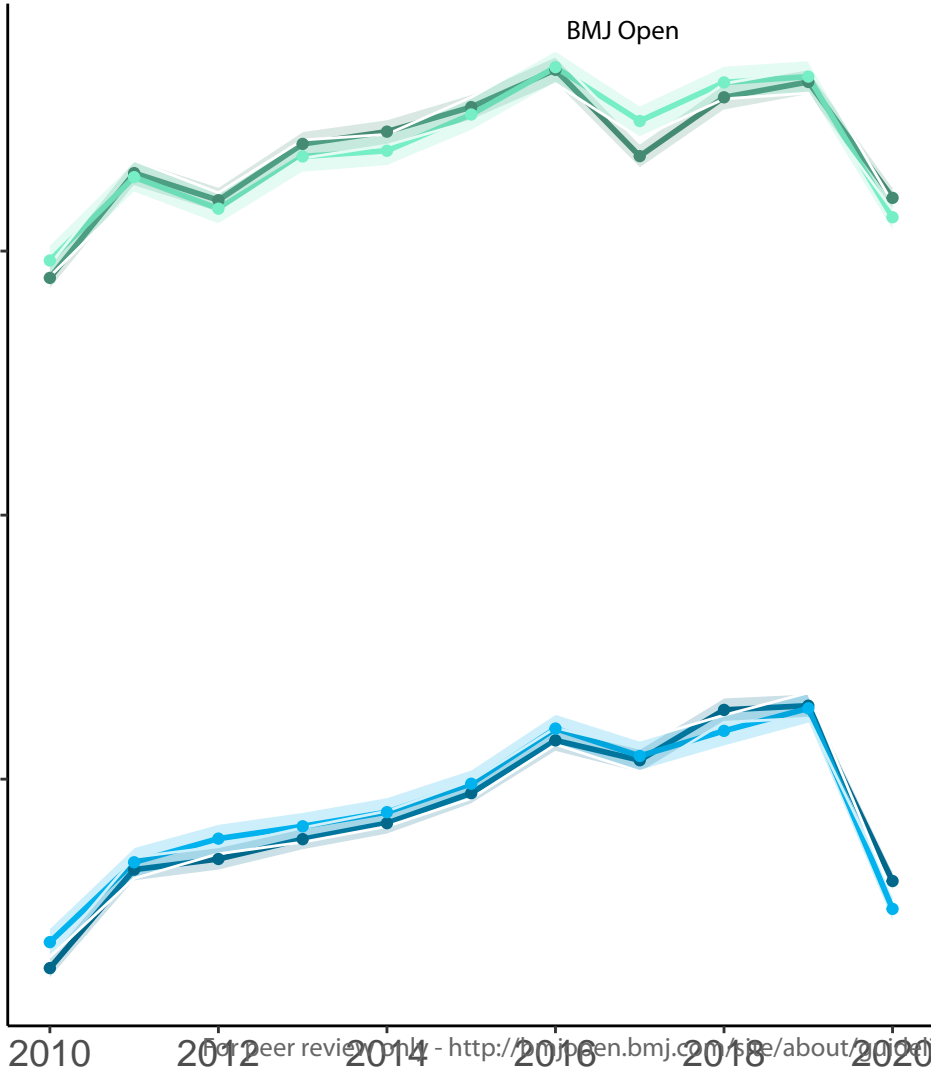
1
2
3 males and females, as a function of poverty. B same as in A, but
4
5 with life expectancy at 65.
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For peer review only

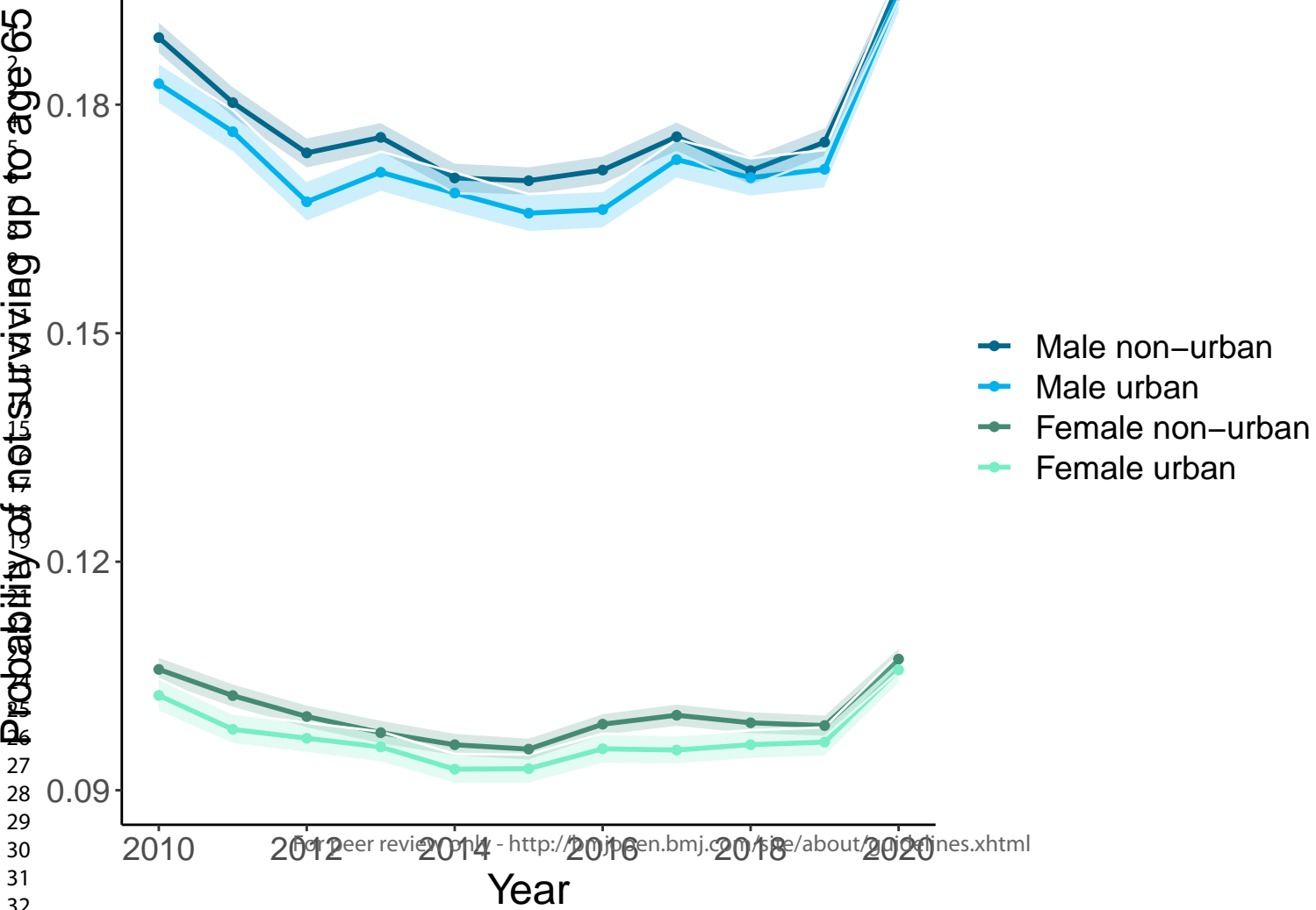
BMJ Open

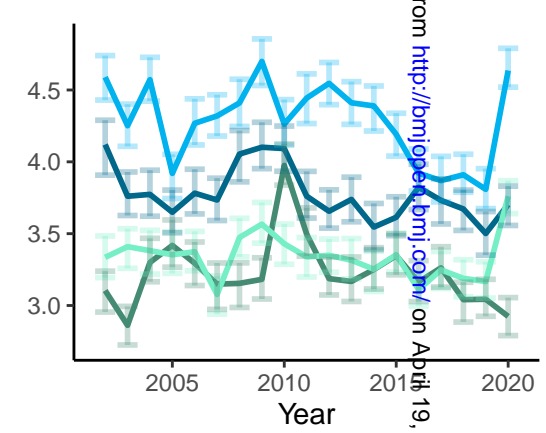
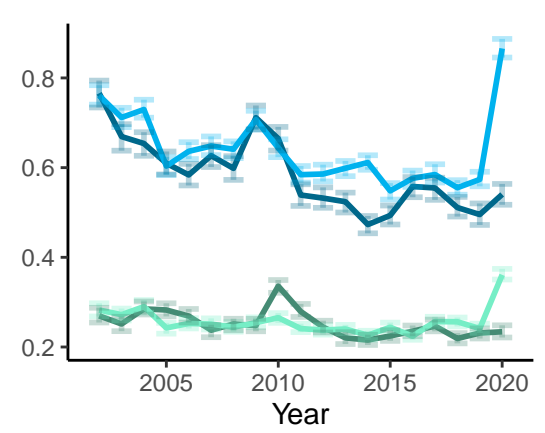
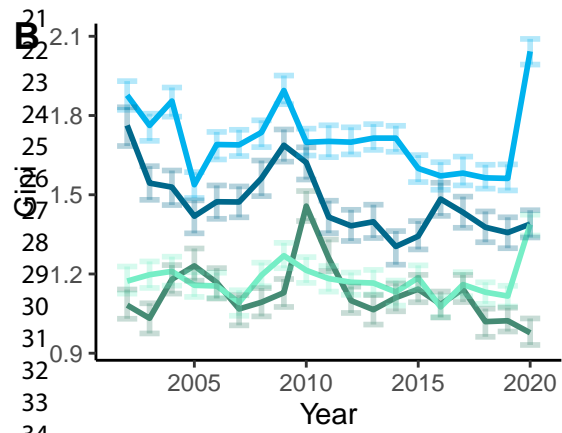
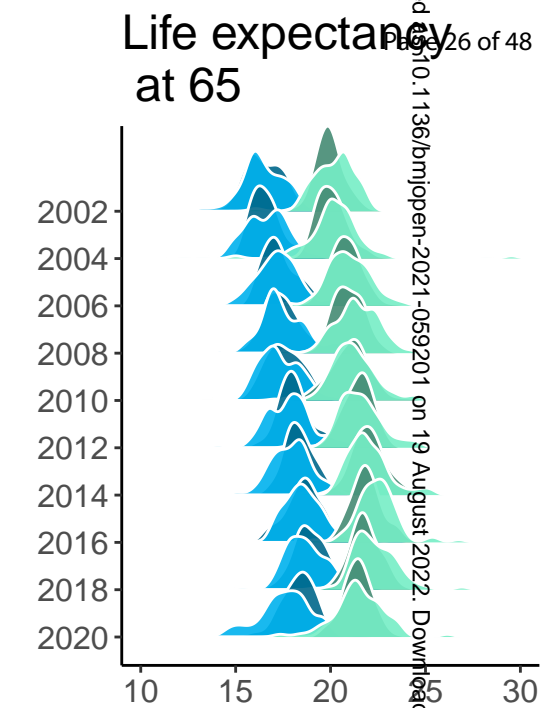
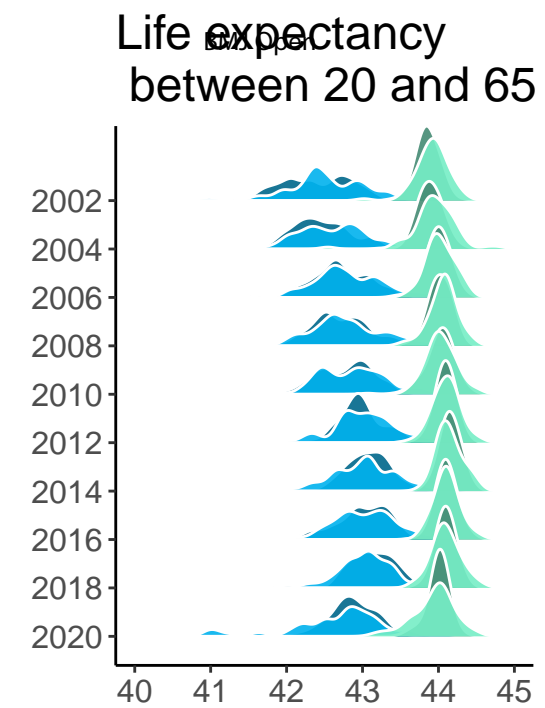
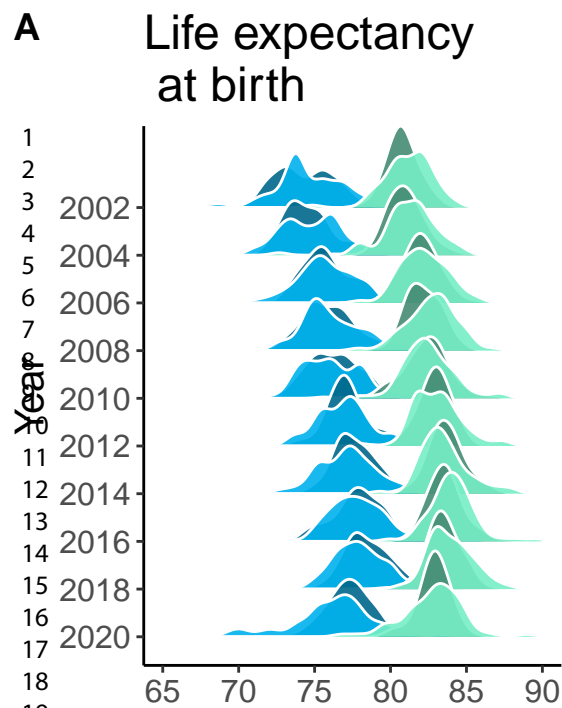
1
2
3
4
5
21
22
23
24
25
26
27
28
29
30
31
32

Life expectancy at birth

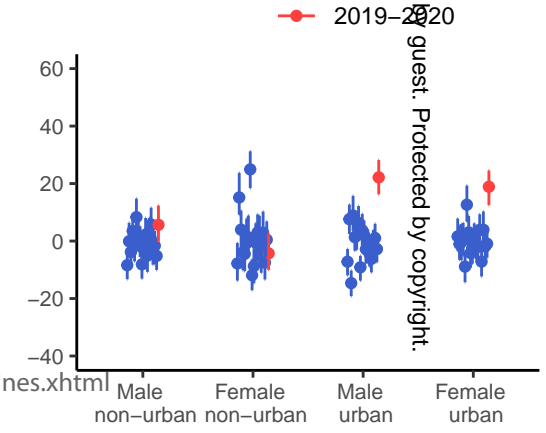
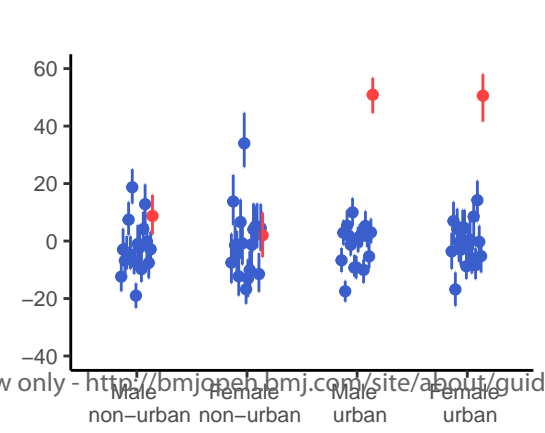
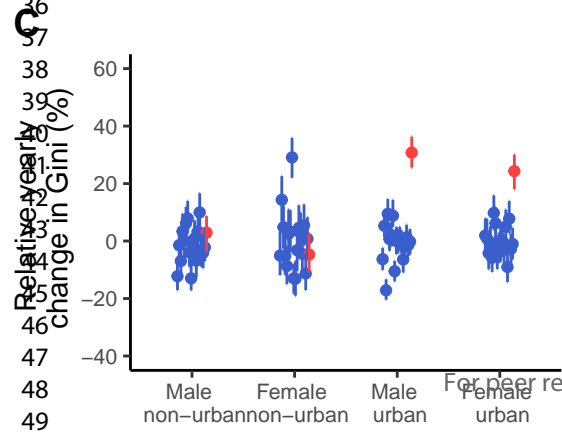


- Male non-urban
- Male urban
- Female non-urban
- Female urban



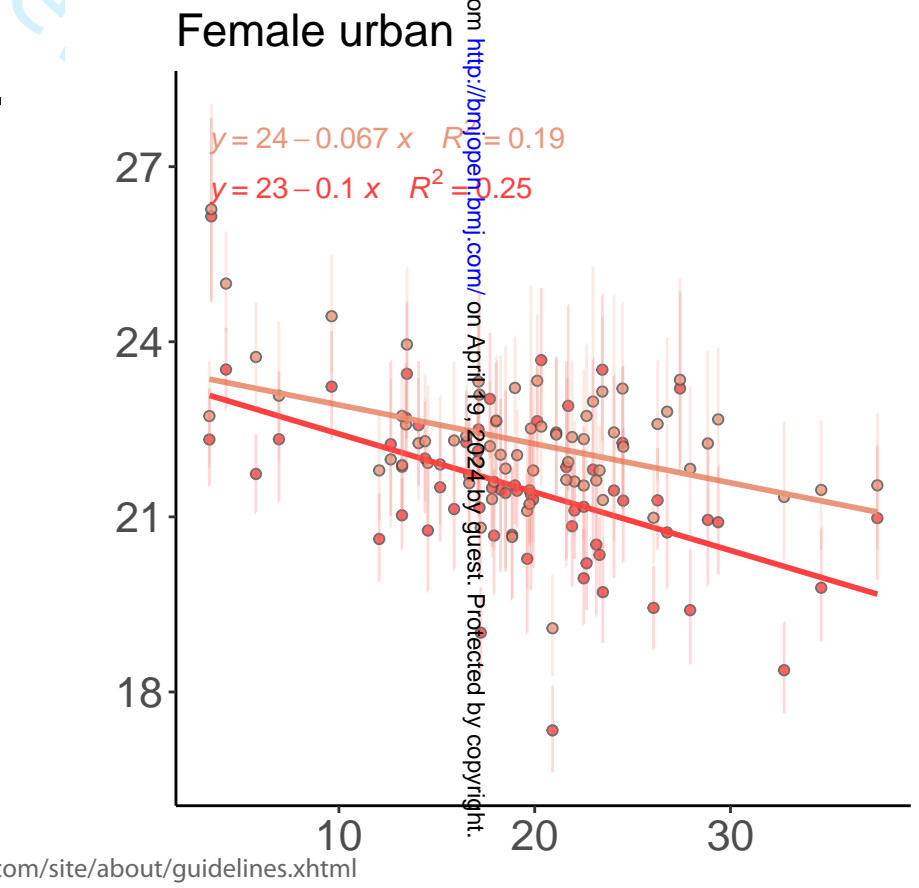
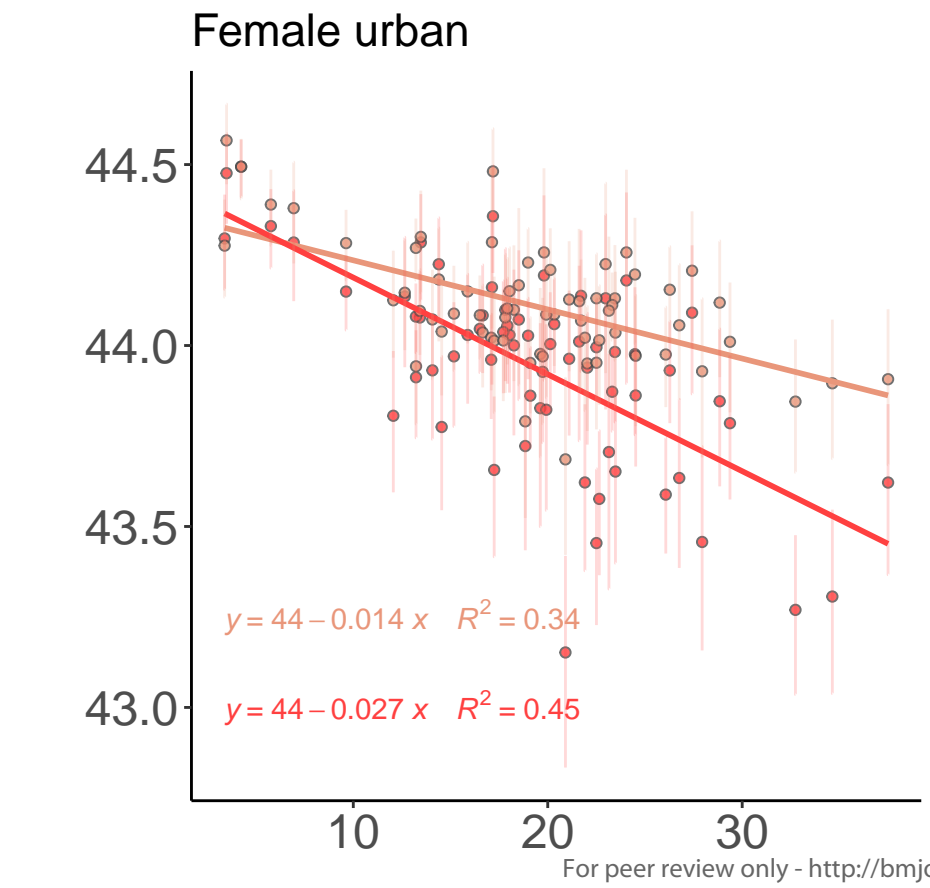
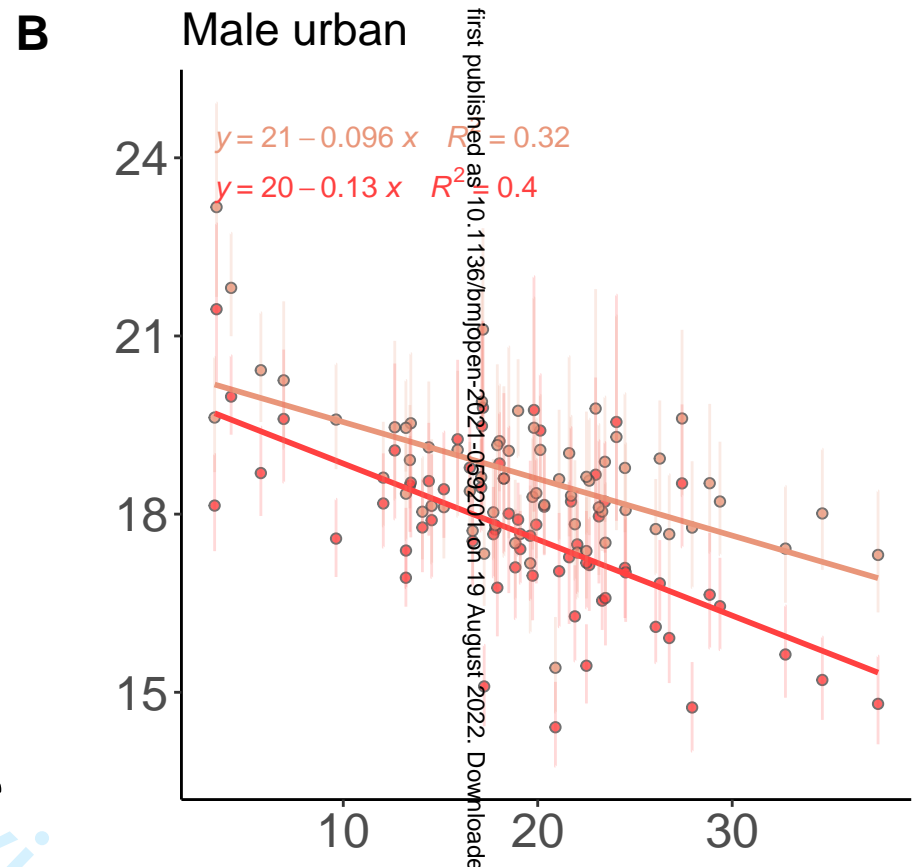
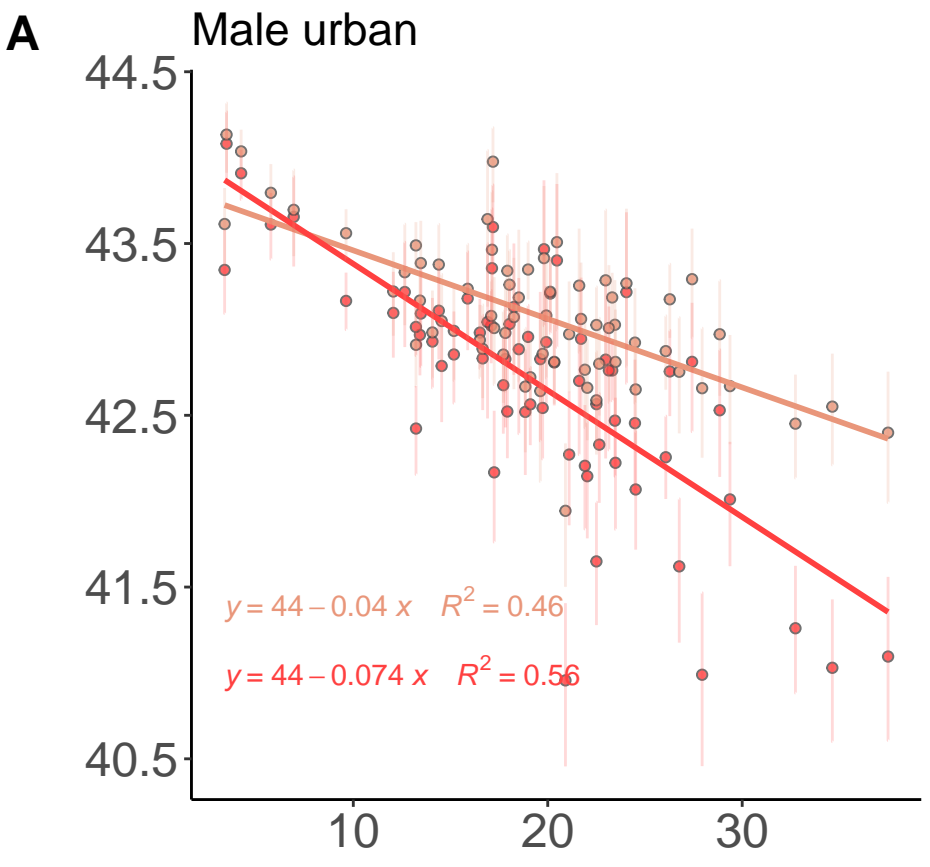


Male non-urban Male urban Female non-urban Female urban



2015–2019 2020

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



Life expectancy at 65

Poverty (%)

BMJ Open: first published as 10.1136/bmjopen-2021-029201 on 19 August 2022. Downloaded from <http://bmjopen.bmj.com/> on April 19, 2024 by guest. Protected by copyright.

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

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 were 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.

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.

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

1
2
3
4
5
6 more, this is an indication that official projections are not accurate, as they become inconsistent
7
8 in 2017 (i.e., official projections in year 2017 are far from official census in the same year).
9

10 **Main results with alternative estimates** In the main text we have used the cohort survival
11 projection method. Here, we present results using the other two alternative methods. Figs. 5
12 and 6 correspond to Exhibits 1 and 2 in the main text, respectively. Figs. 7 and 8 complement
13 Exhibit 3, and likewise, Figs. 9 and 10 complement Exhibit 4.
14
15
16
17
18

19 **5 Additional results**

20
21
22 Fig.11 supplements Exhibit 4 by showing the relation between life expectancy and poverty in
23 non-urban municipalities. No clear consistent pattern is observed. Also, in Fig. 12 we show
24 the corresponding decreases of life expectancy over time as a function of poverty, in urban
25 and non-urban setups. This figure is complemented by Fig. 13, which shows an even stronger
26 correlation when using crowdedness as covariate, and Figs. 14 and 15, which show sensitivity
27 of Fig. 12 to changes in the projection methodology.
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

	Urban	Rural	Excluded	Total
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. Berdegúe, 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].).

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.

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, 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, Valparaíso
Valparaíso	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, Yervas Buenas Curepto, Empedrado, Pelarco, Penciahue, 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, 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, Metropolitana
Metropolitana	Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado, Penaflo, Pirque, San Jose de Maipo, Colina, Lampa, Tiltill, 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.

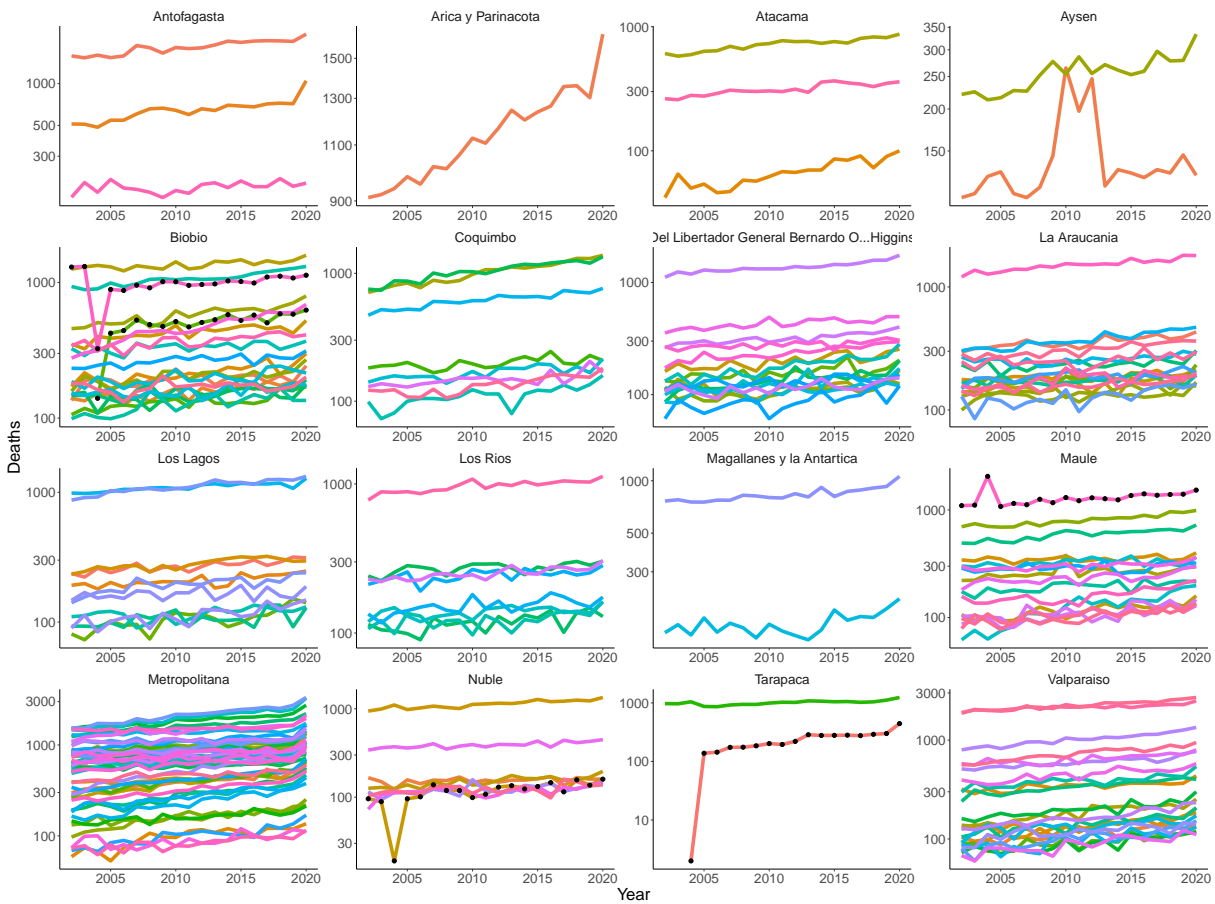


Figure 1: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring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

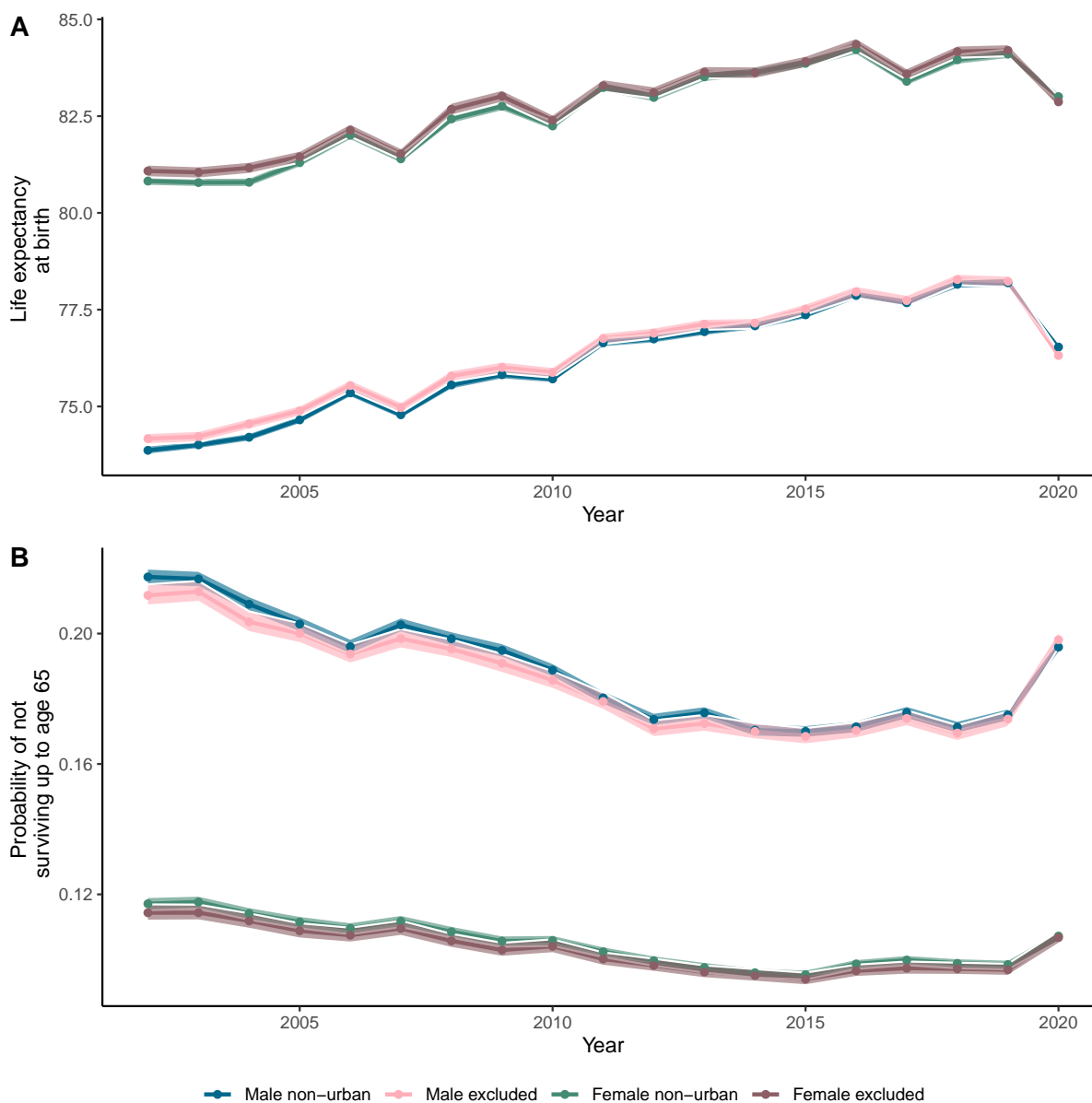


Figure 2: **A.** Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B.** Same as **A**, but with likelihood of dying before reaching 65.

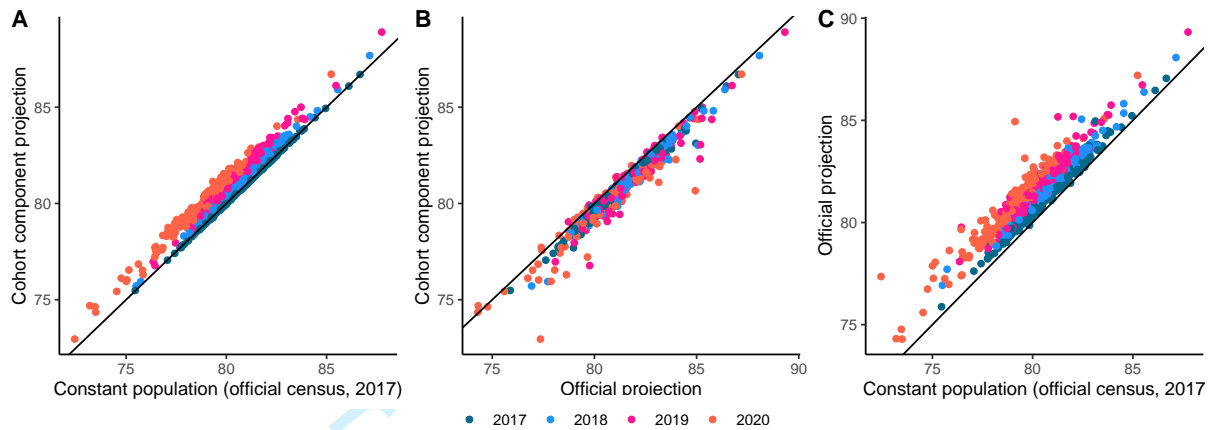


Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival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

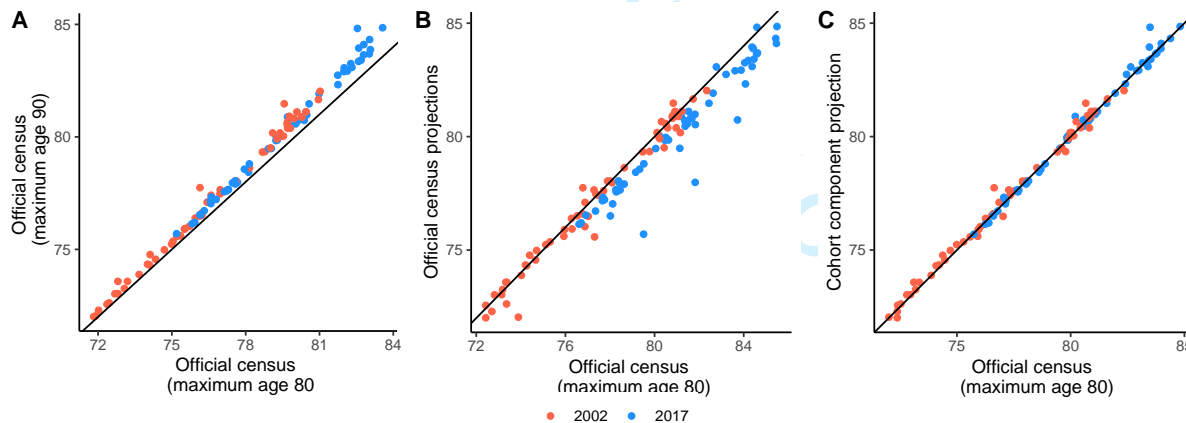


Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with 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.

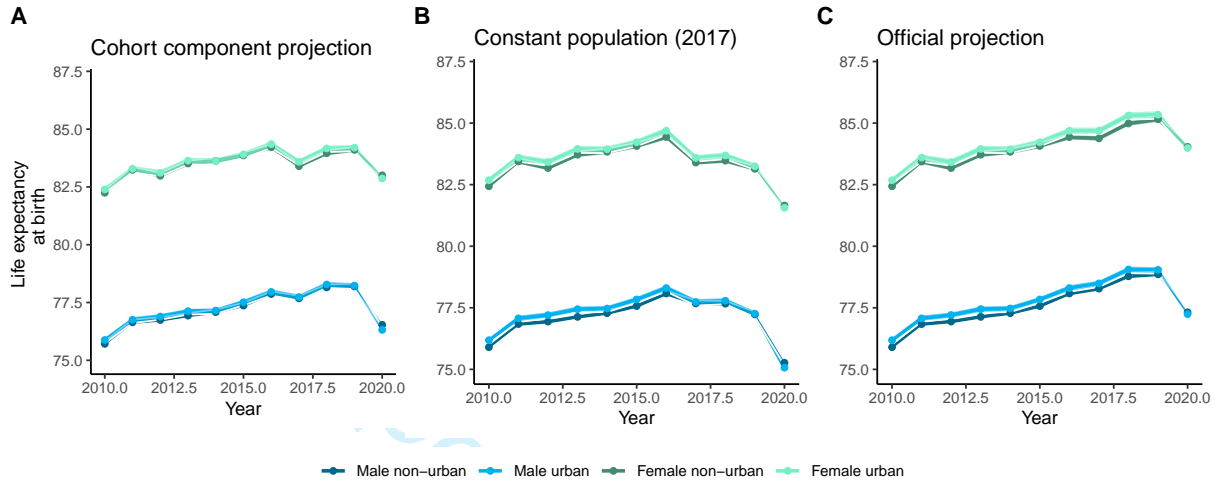


Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with **A**.

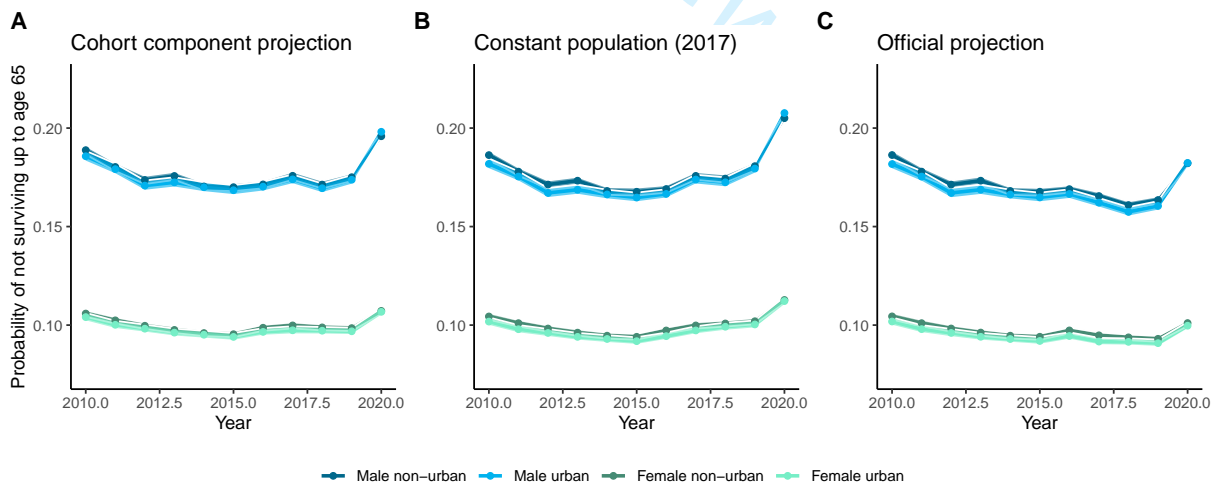


Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with **A**.

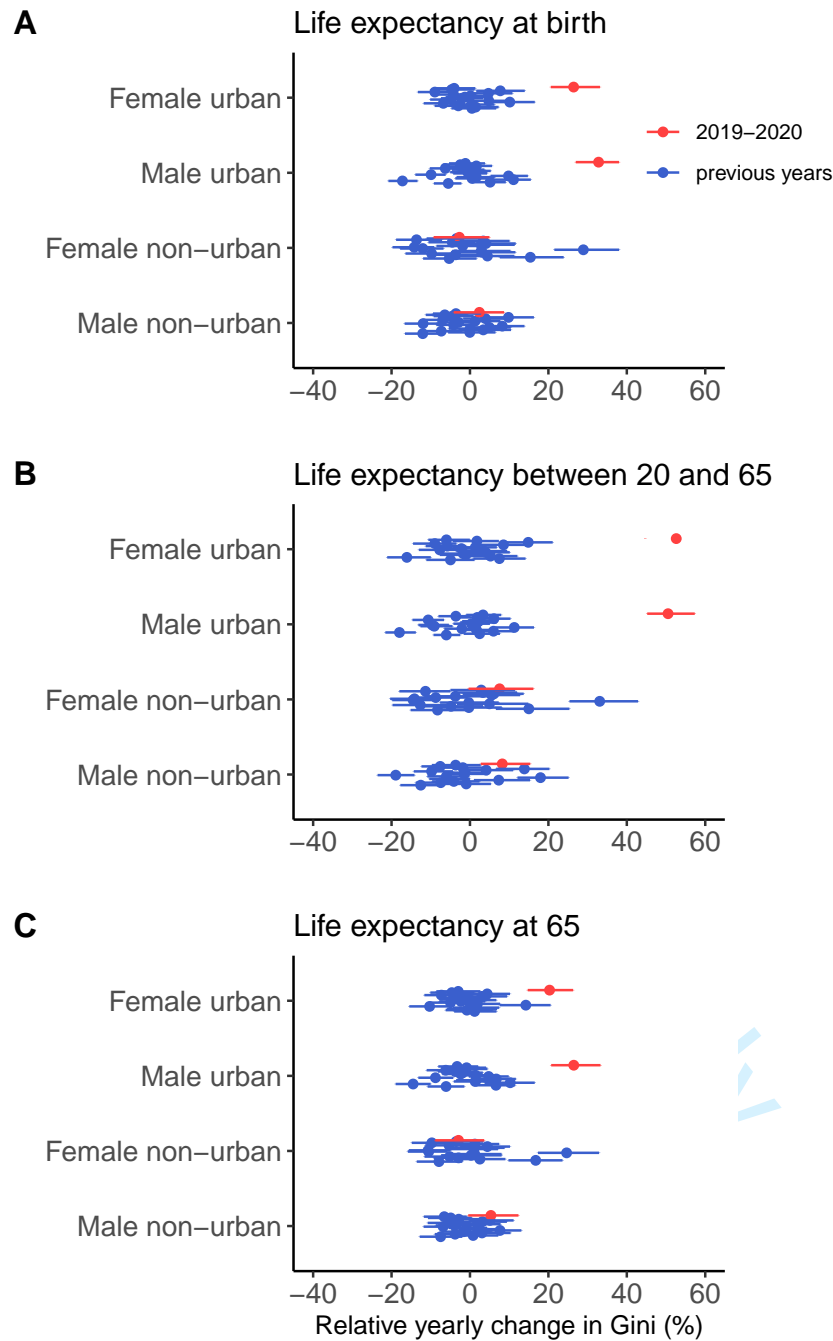


Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

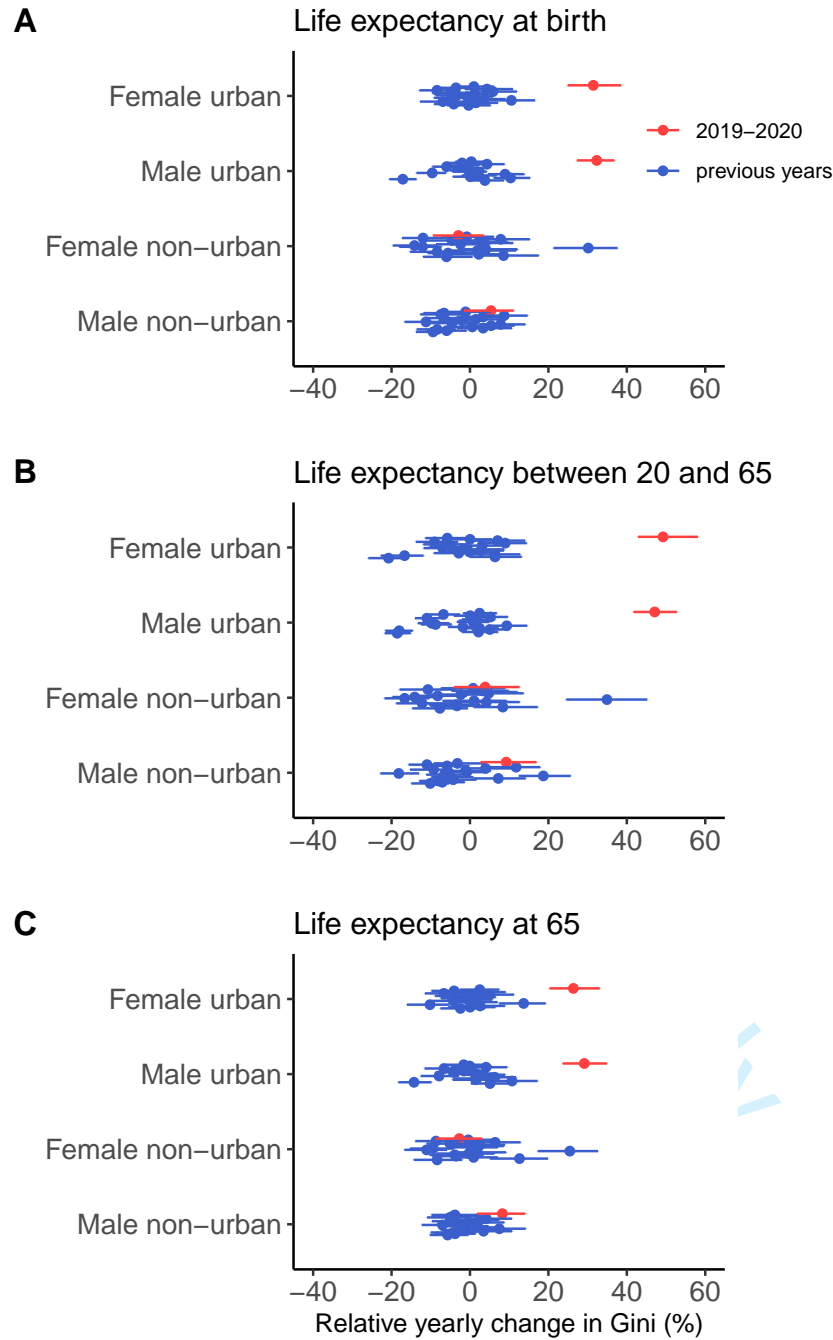


Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

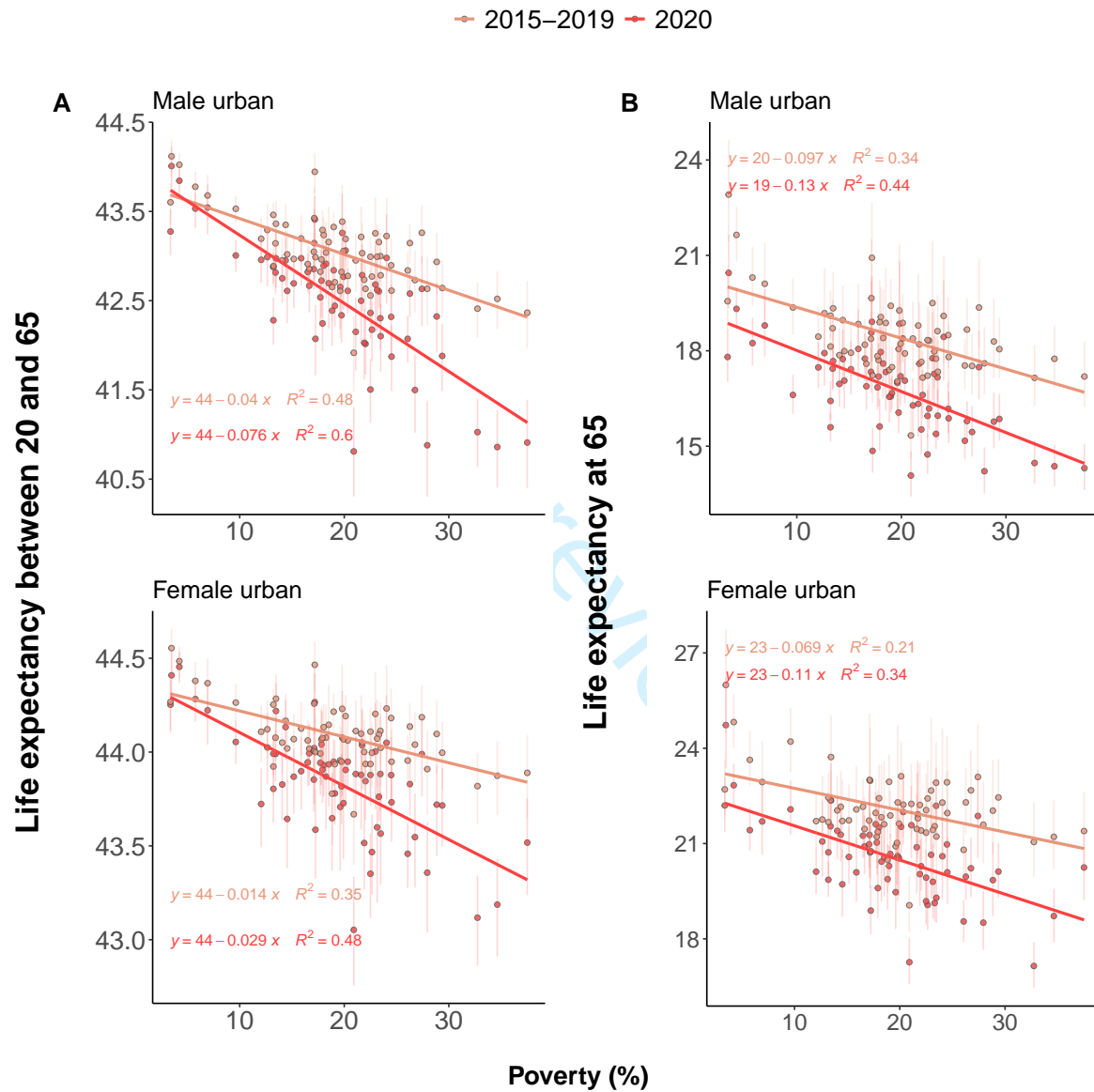


Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019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

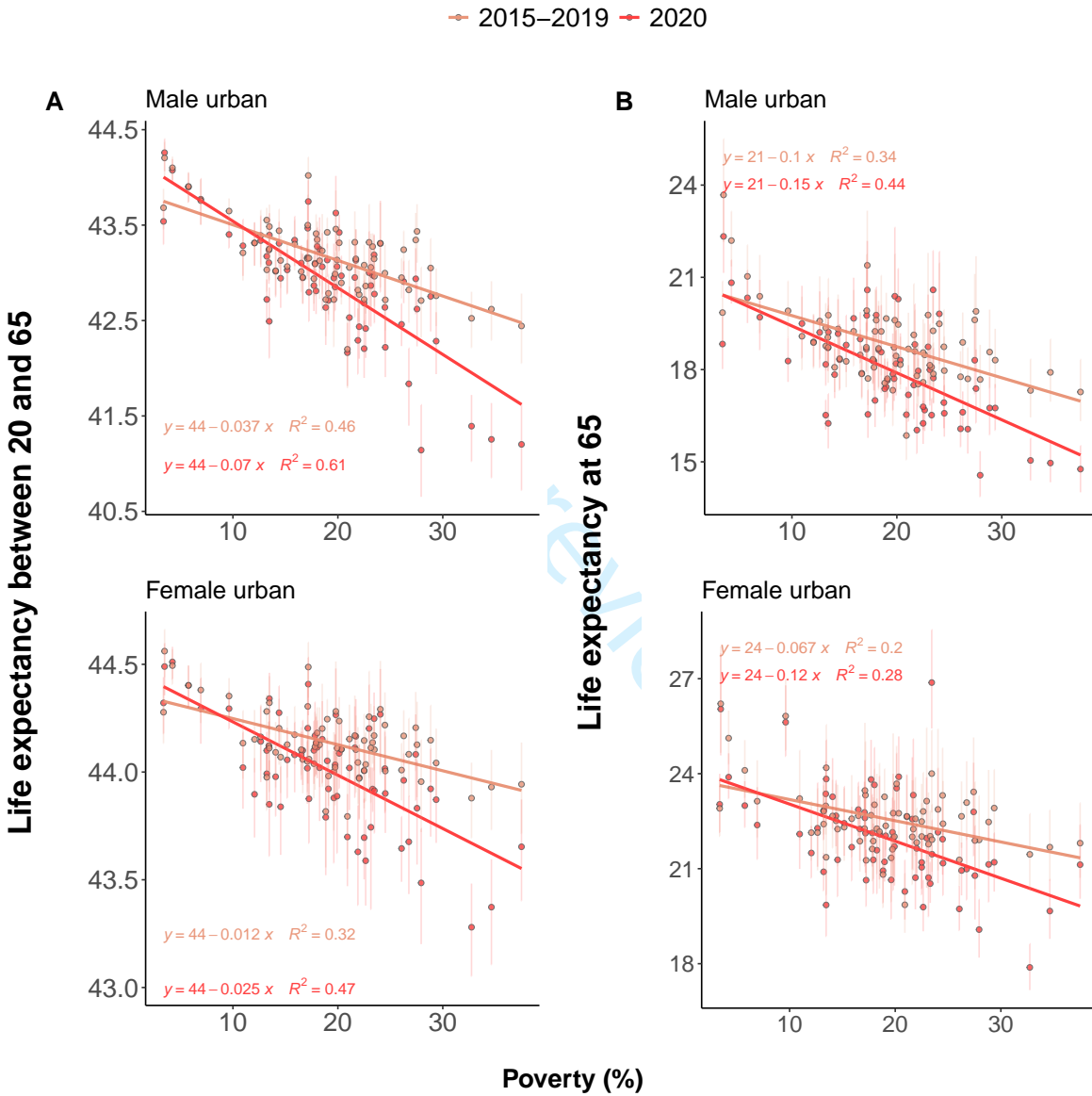


Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

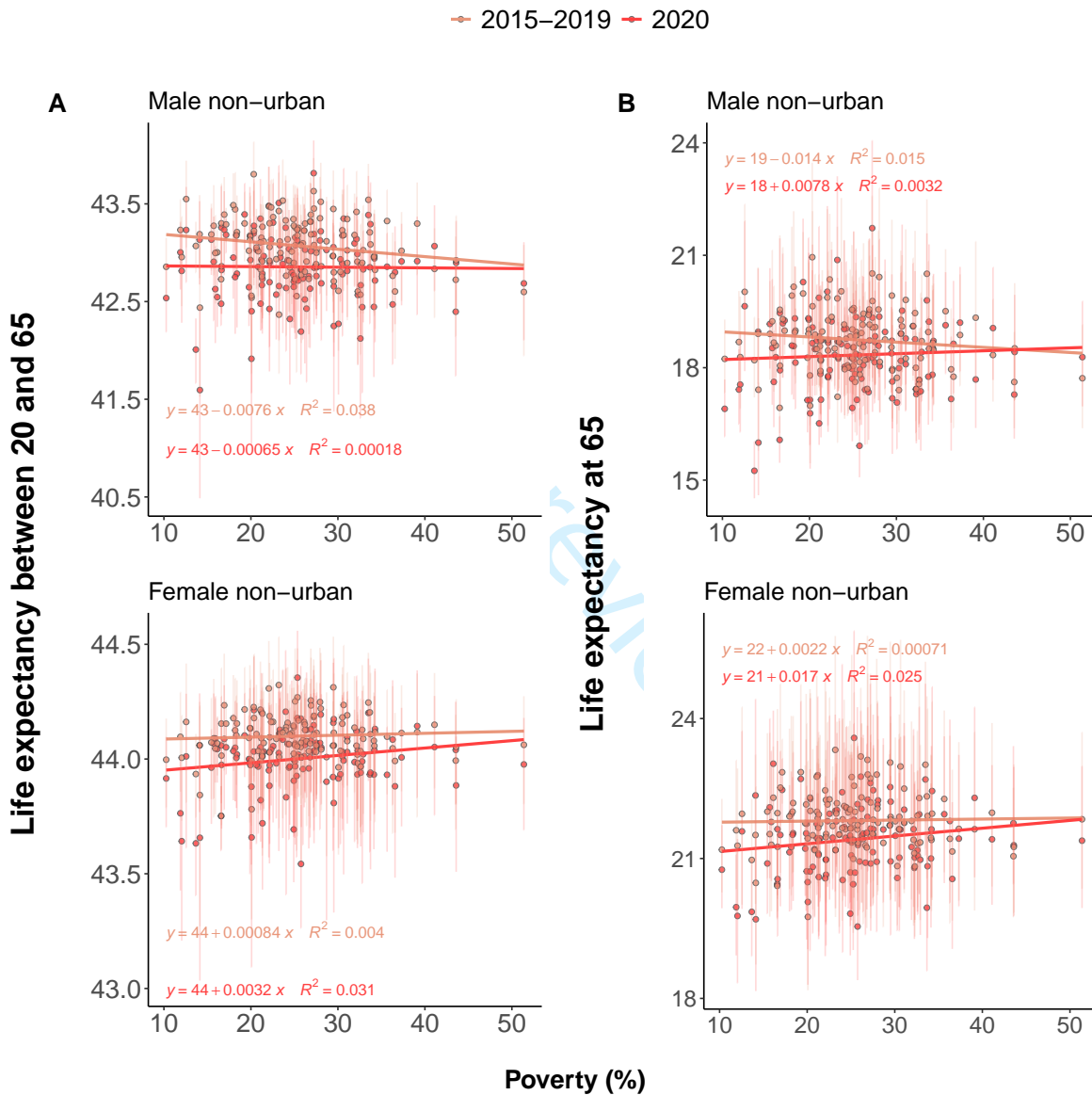


Figure 11: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

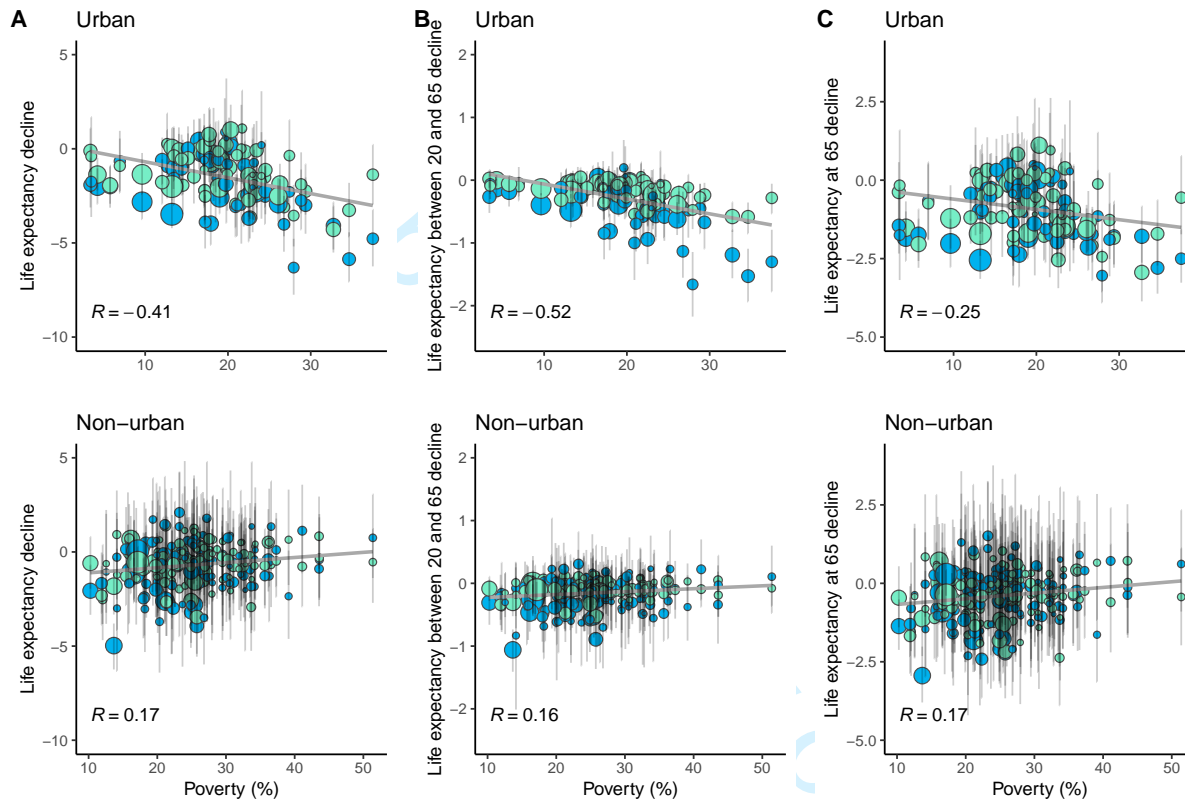
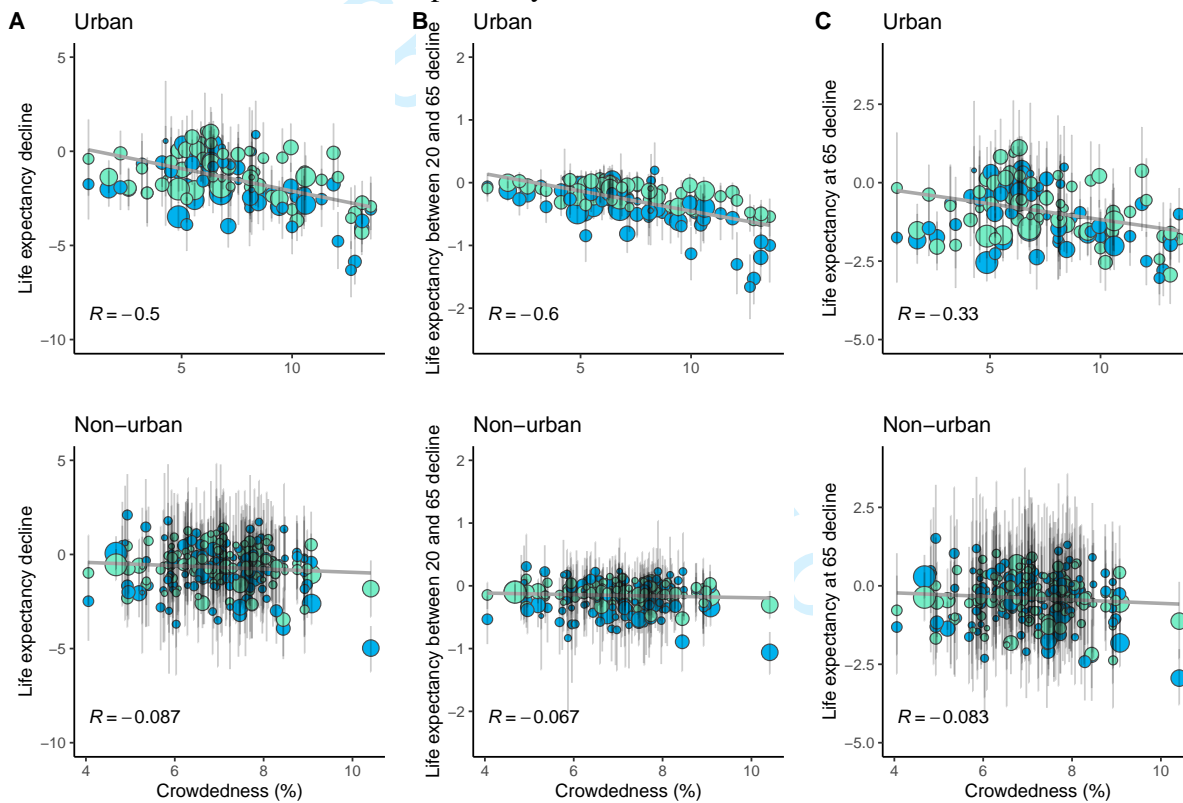


Figure 12: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and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

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.



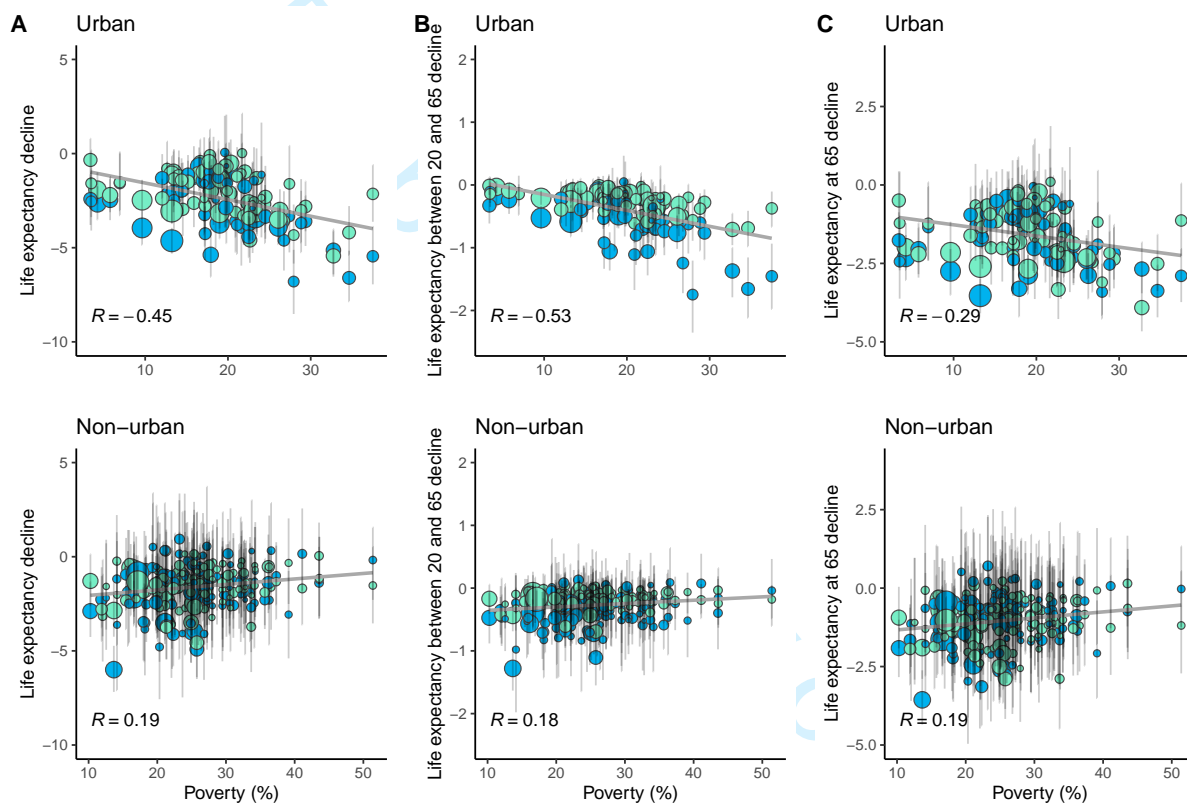


Figure 14: Same as 12 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

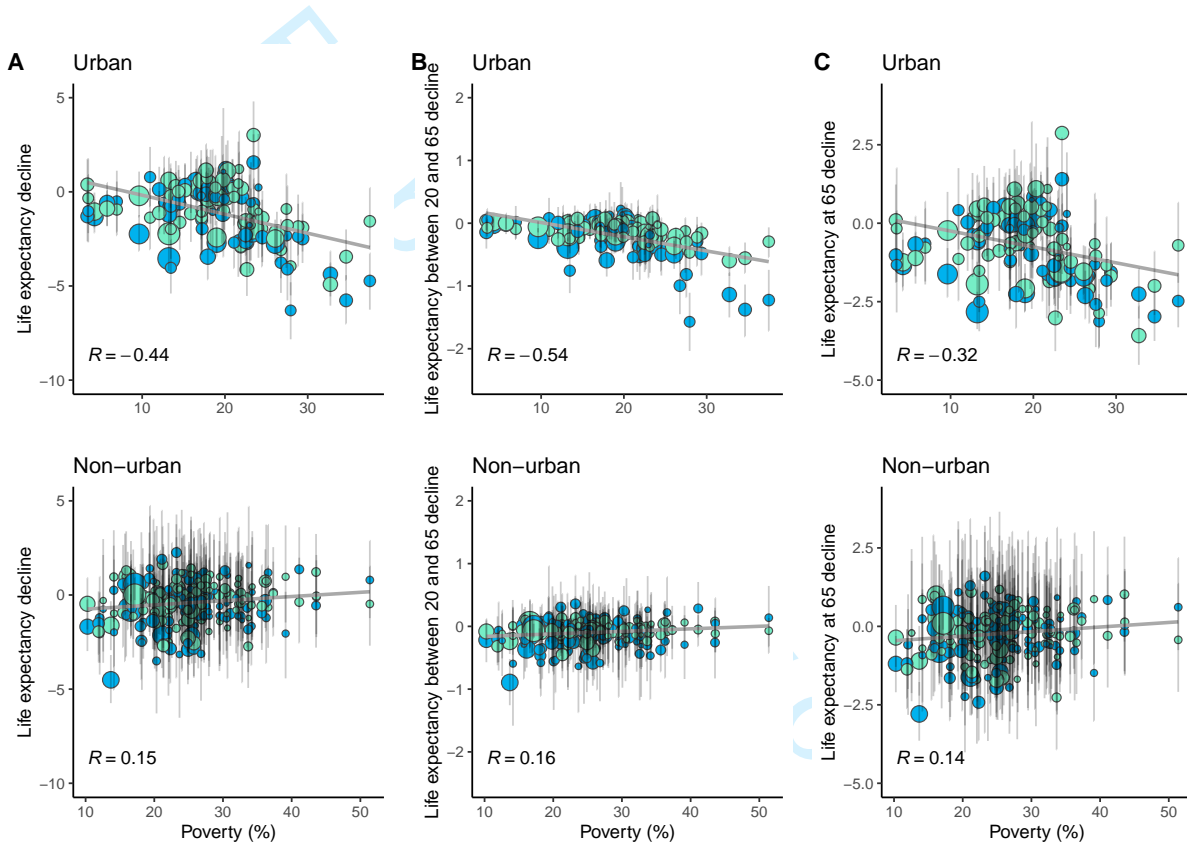


Figure 15: Same as 12 but with population estimates given by official projections.

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

1				
2	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
3			(b) Report category boundaries when continuous variables were categorized	NA
4			(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
5				
6	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-11
7				
8	Discussion			
9	Key results	18	Summarise key results with reference to study objectives	9-11
10	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
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
12	Generalisability	21	Discuss the generalisability (external validity) of the study results	9-11
13				
14	Other information			
15	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
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				

*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.

BMJ Open

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

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2021-059201.R2
Article Type:	Original research
Date Submitted by the Author:	08-Jul-2022
Complete List of Authors:	Mena, Gonzalo ; Oxford University, Statistics Aburto, José Manuel; University of Oxford, Leverhulme Centre for Demographic Science
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Health policy, Infectious diseases, Public health
Keywords:	COVID-19, Demography < TROPICAL MEDICINE, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

1
2
3 **Title:** The unequal impact of the COVID-19 pandemic in 2020 on life
4 expectancy across urban areas in Chile: A cross-sectional
5 demographic study.
6

7
8 **Authors:** Gonzalo E. Mena^{1,*}, José Manuel Aburto^{2,3,4}
9

10 **Affiliations:**
11

12 ¹Department of Statistics, University of Oxford; Oxford, UK (Email:
13 gonzalo.mena@stats.ox.ac.uk)
14

15
16 ²Leverhulme Centre for Demographic Science and Nuffield College,
17 University of Oxford; Oxford, UK (Email: [jose-](mailto:jose-manuel.aburto@sociology.ox.ac.uk)
18 manuel.aburto@sociology.ox.ac.uk)
19

20
21 ³London School of Hygiene and Tropical Medicine, London, UK.
22

23 ⁴Interdisciplinary Centre on Population Dynamics, University of
24 Southern Denmark; Odense 5000, Denmark.
25

26
27 *Corresponding author.
28
29

30 **Word count (main text, references):** 3229
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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.

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

1
2
3 stronger during the pandemic. In support of this hypothesis, recent
4 research in Chile's Capital showed a strong negative correlation
5 between excess deaths and socioeconomic status. This correlation was
6 particularly stark among younger age-groups but eventually evened
7 out for the elderly.⁶ Since younger ages affect more life
8 expectancy, it is likely that excess young-age mortality may have
9 increased inequality in life expectancy. Alternatively, since death
10 rates increased exponentially with age and losses in life expectancy
11 in low mortality countries have been attributed mostly to mortality
12 above age 60,⁵ it is likely that the pandemic in 2020 was such a
13 strong shock that excess mortality differentials decreased, leading
14 to reducing inequalities between municipalities.
15
16
17

18
19 This article contributes towards a more comprehensive understanding
20 of the COVID-19 pandemic's burden on population health by estimating
21 life expectancy across Chilean municipalities by sex using a
22 powerful Bayesian methodology.¹⁴ We contextualize our results with
23 past trends of progress and disparities in life expectancy, and
24 comment on the the relevance of acknowledging such persisting
25 disparities in the design of social security mechanisms. Our study
26 is a step towards explaining the varied impacts of the pandemic by
27 analyzing trends in life expectancy over age at a more granular
28 level and by correlating life expectancy losses with indicators of
29 poverty in Chile.
30
31
32
33

34 **Study Data and Methods**

35 **Data**

36
37
38 We used data on births and deaths by age, sex and municipality from
39 publicly available vital statistics.¹⁵ These data were complemented
40 with official population counts by age (single years of age from 0
41 to 89 and collapsed in 90+), sex and municipality from the 2002 and
42 2017 censuses available from the National Institute of Statistics
43 (INE).¹⁶ We also used official population projections between 2002
44 and 2020 centered at the 2017 census.¹⁷ Unlike censuses, these
45 projections collapsed all ages greater than 80 in one single group.
46 We only observed minor changes in our estimates based on whether the
47 open ended interval started at 80 or 90, but we did observe that
48 life expectancy estimates based on 2017 projections were
49 substantially higher than the ones based on the 2017 census. We
50 explain this by a possible inadequacy of the official projection for
51 later years. Because of this reason, we considered two alternative
52 population estimates for 2017 onwards. The first one assumes that
53 population counts remain fixed for years 2018, 2019 and 2020. In the
54 second one, we projected forward the population using the cohort
55 component method¹⁸ with 2017 as baseline assuming zero migration. We
56
57
58
59
60

1
2
3 also used census data to classify municipalities as urban or non-
4 urban,¹⁹ if the following two conditions held: i) population density
5 greater than 70 people per square kilometer, and ii) the proportion
6 of people living in an urban environment is greater than 88%. Chile
7 is made up of 366 municipalities and according to this criteria, 35%
8 are classified as urban, making up for 65% of the population
9 (17,539,805, as per the 2017 Census). See Supplementary Tables 1-3
10 for details. Data on poverty and crowdedness were taken from the
11 CASEN survey by the Chilean Ministry of Social Development and
12 Family.²⁰ CASEN is the most comprehensive official poverty survey
13 available in Chile. For poverty, we used the 'multidimensional
14 poverty' indicator. In CASEN, a household is defined to suffer from
15 multidimensional poverty if it accumulates 22.5% of deprivation
16 according to a weighted score that takes into account 15 variables
17 including income, access to healthcare, labor, social security,
18 housing and social cohesion among others. Likewise, a household is
19 considered crowded if there are 2.5 or more people per room. All
20 data used in our analyses have been compiled and made publicly
21 available²¹.

22 23 24 25 26 27 28 **Mortality estimation**

29
30 We performed mortality analyses at the municipality level since this
31 is the finest spatial unit at which age and sex specific demographic
32 data and covariates (poverty, crowdedness) are available. By
33 considering municipalities as units we are able to investigate the
34 variation of the resulting distribution of mortality and its
35 relation with other covariates (e.g. age, urbanity status, poverty).
36 Age specific death rates for each municipality by sex were estimated
37 implementing a recently developed methodology¹⁴ based on a
38 hierarchical Bayesian model²² using population and death counts.
39 There are two main advantages to this Bayesian methodology: first,
40 the fact that municipality specific rates are assumed to be samples
41 from a population with global parameters enables the sharing of
42 information between municipalities, helping to smooth out the noisy
43 estimates that would otherwise be obtained if we relied only on
44 empirical counts. This is important because of the increased
45 likelihood of low death counts on each strata in small
46 municipalities. Second, by appealing to the Bayesian methodology we
47 immediately obtain credible intervals for each of our
48 estimates. [Updating](#)

49 50 51 52 53 54 **Life tables**

55
56 Life tables were calculated using the age specific death rates
57 estimated in the Bayesian procedure following standard techniques.¹⁸
58 From these, period life expectancy at birth, temporary life
59
60

1
2
3 expectancy between ages 20 and 65, and remaining life expectancy at
4 age 65 were obtained. Life expectancy at birth refers to the average
5 years a cohort of newborns is expected to live given the current
6 mortality conditions. Similarly, life expectancy at age 65 refers to
7 the average years individuals aged 65 are expected to live if they
8 were to experience the current mortality conditions throughout their
9 lives. Given the emerging evidence about how younger age groups
10 below age 65 have also been affected by the pandemic in the context
11 of Chile, we constructed a measure to capture average longevity over
12 working ages through temporary life expectancy. Temporary life
13 expectancy between ages 20 and 65 refers to the average years lived
14 between these ages given prevalent mortality conditions.²³ For
15 example, if no one were to die between these ages, then the
16 temporary life expectancy would be the full 45 years. To complement
17 our analysis we also consider the probability of dying before age 65
18 as an indicator of premature mortality.
19
20
21
22

23 **Measuring heterogeneity**

24
25
26 We leverage the availability of life expectancy estimates at the
27 municipality level to conceive a fictitious population where each
28 municipality is a sample. We quantify the heterogeneity of this
29 population through the Gini coefficient.²⁴ The Gini coefficient is a
30 standard indicator of inequality employed in social sciences. In the
31 context of this paper, the Gini coefficient expresses the degree of
32 inequality in life expectancy across municipalities. With our
33 methodology, we can seamlessly quantify temporal changes of the Gini
34 for different strata (male/female, urban/non-urban) and report
35 credible intervals.
36
37
38

39 **Patient and Public Involvement**

40 No patients were involved in this paper, all the analyses are based
41 on aggregated data.
42
43
44

45 **Results**

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

48
49 Males and females from both urban and non-urban areas experienced
50 steady increases in life expectancy at birth from 2010 to 2019.
51 Females showed higher life expectancy at birth than males in all
52 groups. In contrast, higher mortality during 2020 led to sharp
53 decreases in life expectancy at birth (Figure 1) compared to 2019.
54 Life expectancy among males in urban and non-urban areas declined by
55 1.89 (95% CI: 1.68,2.09) and 1.66 (1.50,1.80) years, respectively.
56 Among females, life expectancy losses were 1.33 (1.11,1.55) and 1.10
57 (0.92,1.28) years, respectively. The magnitude of the decline from
58
59
60

1
2
3 2019 to 2020 offset most gains in life expectancy experienced in the
4 last decade, especially in urban areas. In fact, 68% of the
5 municipalities analyzed ended up with lower life expectancy than in
6 2015, and this number rose to 75% in urban municipalities. In terms
7 of individuals, 76% (non-urban) and 78% (urban) of the population
8 lived in a municipality that faced a decline in life expectancy
9 compared to 2015.
10
11

12 Declines in the probability of surviving to age 65 (Figure 2)
13 between 2019 and 2020 indicate that changes in life expectancy
14 cannot be fully attributed to increased mortality in older age
15 groups only. While mortality above age 65 has been documented as one
16 of the main contributors to declines in life expectancy
17 internationally, substantial increases in mortality below age 65 are
18 apparent in our results, especially among males in urban areas.
19
20
21

22 ***Changes in disparities in life expectancy during the COVID-19*** 23 ***pandemic in 2020*** 24

25
26 Figure 3 shows the time evolution of the inequality in life
27 expectancies across municipalities, and shows the striking impact of
28 COVID-19 on this quantity. Inequality increased in urban areas from
29 2019 to 2020, with changes oscillating around 25%, a rate not seen
30 in the recent past. The magnitude of increase is much larger in male
31 and female life expectancy between ages 20 and 65 from urban areas
32 (50.9% and 50.6% for males and females respectively). Contrarily, in
33 non-urban areas we do not observe changes deviating significantly
34 from usual year-to-year fluctuations. Altogether, these results
35 indicate not only that mortality during 2020 became more unequal,
36 but that this inequality was driven mostly by the younger age group.
37
38
39

40 Histograms in Figure 3 suggest that the abrupt increase in
41 inequality during 2020 can be attributed to heavier left tails of
42 the life expectancy distribution, indicating an increase in the
43 amount of municipalities with a much lower-than-average life
44 expectancy. To better understand the factors driving this spike in
45 inequality, we investigated how declines in life expectancy during
46 2020 correlated with social deprivation indicators including poverty
47 and crowdedness focusing only on mortality above age 20 across urban
48 areas. Figure 4 shows the negative association between poverty and
49 life expectancy between age 20 and 65, and life expectancy at age
50 65. To underscore how the relationship changed in the course of
51 2020, we stratified the results juxtaposing the previous five years
52 (2015–19) with 2019–20. Results show a strong historical negative
53 correlation between life expectancies in both age groups, sexes and
54 poverty levels. Males in the top poverty decile have a 4.39-years
55 lower life expectancy than in the bottom decile. They also live on
56 average 0.92 less years between 20 and 65, and 2.22 from 65 onwards.
57
58
59
60

1
2
3 For females, these numbers are 2.51, 0.31 and 1.55 years. During
4 2020, the slope decreased, suggesting that those municipalities with
5 higher levels of poverty experienced greater losses in life
6 expectancy. This dependency was stronger in the younger age group.
7

8
9 In contrast, while life expectancy at 65 declined during 2020, this
10 decline was less unequal over the poverty gradient, consistent with
11 the hypothesis that this group contributed less to inequality in
12 changes in life expectancy. To formalize these observations, we
13 performed regression analyses to model the interactions between year
14 and poverty level through varying intercepts and slopes. We only
15 found significant changes in the slope for average years lived
16 between 20 and 65. For males, this translated into an additional
17 difference of 0.78 years between the highest and lowest poverty
18 deciles ($p=0$). For females, this difference was 0.30 ($p<0.001$).
19
20
21

22 Discussion

23
24 Urban areas that are exposed to higher poverty or social
25 disadvantages experienced larger losses in life expectancy during
26 the COVID-19 crisis in 2020 in Chile. Our results reveal that losses
27 were unevenly shared across municipalities, over age, and by sex,
28 leading to increasing inequality in life expectancy across regions
29 in Chile. Moreover, consistent with previous research on increased
30 mortality at younger ages in 2020 in deprived municipalities in
31 Chile's capital,⁶ our research shows that working age mortality was
32 one of the main drivers of increasing inequality in life expectancy
33 across Chile.
34
35
36

37
38 Analysis of life expectancy in 2020 compared with the previous five
39 years (2015-19) show that poorer urban municipalities suffered a
40 double burden. Not only did they show lower levels of life
41 expectancy but they also experienced greater losses in life
42 expectancy. This is consistent with previous research documenting
43 larger mortality increases for the lower educated groups in Chile's
44 capital.²⁵ Furthermore, when we disaggregate by age groups, we
45 observe that the association between life expectancy for working age
46 individuals (between ages 20 and 65) and levels of poverty became
47 stronger compared to previous years. This is consistent with
48 previous evidence had documented a positive association between
49 income and life expectancy at retirement.²⁶ This suggests that even
50 if the burden of mortality during the COVID-19 crisis has been
51 concentrated at older ages,²⁷ contributing substantially to life
52 expectancy declines during 2020,²⁸ inequalities in life expectancy
53 were largely driven by increased mortality in working ages at higher
54 levels of poverty. A potential explanation is that the working age
55 population's availability to work from home and be less exposed to
56 heightened risk of COVID-19 and its consequences varies across
57
58
59
60

1
2
3 poverty levels. Deprived populations in Chile's capital experienced
4 higher fatality rates as a consequence of worse baseline individual
5 health status and to an overwhelmed healthcare system.⁶ Similarly,
6 evidence from the US suggests that those individuals with less
7 availability to work from home had higher death rates compared to
8 those that could afford working from home in 2020.²⁹
9
10

11 An open question is whether this sudden increase in inequality
12 amounts to a shock that will be followed by a recovery to pre-
13 pandemic levels, or whether these changes will persist in the long
14 term. Beyond the immediate increase in premature mortality, this is
15 relevant because failing to acknowledge inequalities in mortality
16 may compromise the progressiveness and actuarial fairness of social
17 security and public pension systems in the long term,^{30,31} which could
18 be translated into higher mortality in the future. Similarly, the
19 scars left by the pandemic, including a weak health system, may
20 increase mortality from multiple causes of death. For example,
21 postponed cancer treatments and failure to detect other chronic
22 degenerative diseases timely may lead to lower levels of life
23 expectancy in the long term than it was projected. This highlights
24 the need for accurate and timely data on other causes of death.
25 Future analysis should focus on analyzing the consequences of the
26 COVID-19 pandemic, including multiple causes of death and diseases
27 to study the direct impacts from COVID-19 mortality as well as the
28 indirect impacts through other pathways of diseases and conditions.³²
29 Our research, in this sense, provides a first outlook by focusing on
30 all-cause mortality.
31
32
33
34
35

36 As shown by our results, the case of Chile underscores the dire
37 widening of an already large mortality gap between those living in
38 deprived conditions and those living with higher income during the
39 COVID-19 crisis. Evidence shows that the health consequences of
40 external shocks such a pandemic or an economic crisis are not spread
41 equally across social deprivation levels.³³ The COVID-19 pandemic
42 reminds us of the ever-present risk of such events, whose cumulative
43 impact may partially explain the ever-existing gaps in mortality.
44 Therefore, the way that this crisis has exposed the vulnerabilities
45 of socially deprived populations is a call to challenge the
46 monolithic view of a country's demographics in the design of social
47 security systems. New strategies incorporating a public health
48 perspective that considers widening inequalities should be
49 implemented to minimize the impacts of the COVID-19 pandemic on the
50 health status of the Chilean population both immediately and in the
51 long term.
52
53
54
55
56

57 **Limitations**

58
59
60

1
2
3 This study had several limitations. First, while Chile's vital
4 registration is one of the most reliable in Latin America, there are
5 likely to be inaccuracies in mortality registration due to age
6 misreporting and coverage across municipalities, as well as
7 systematic age overstatement.³⁴ Delays in recording deaths may lead
8 to incompleteness issues especially in urban areas. Our results on
9 life expectancy declines and mortality inequalities may be
10 considered a lower bound because of these issues. The effect of
11 systematic age overstatement is likely to affect our results too.
12 However, there is no information on what the age pattern of
13 overstatement is during the pandemic. To mitigate these inaccuracies
14 and their effects on life expectancy estimates, we used a
15 hierarchical Bayesian model that helped to retrieve a reasonable
16 mortality profile across regions. Another limitation is that because
17 of the low number of deaths observed in some municipalities, the
18 degree of uncertainty around the estimates was very high, not
19 allowing us to include them in our analysis with confidence. We
20 excluded municipalities by sex with less than 16,000 people (as per
21 the 2017 census), as we observed that life expectancy estimates were
22 unstable even with our adopted Bayesian methodology. However, we
23 grouped them together and reproduced all results to avoid systematic
24 exclusion. Results were consistent and are shown in Supplementary
25 Figure 1. Almost all of these were non-urban municipalities. Some
26 other six municipalities were excluded in 2004 based on a visual
27 inspection of mortality trends that were clearly indicative of
28 coding errors in the mortality database (see Supplementary Figure 2)
29 during that year. Despite these limitations, we used the most
30 reliable data for Chile and state-of-the-art methodologies to gauge
31 mortality dynamics across Chile. Additionally, our results are
32 limited in that stratified population counts are typically model-
33 based estimates (except at census years), and might be biased. We
34 studied the effect of alternative population estimates in final
35 outcome measures, as described in the Supplement (Figures 3-15).
36 Finally, because of our observational study design, we are only able
37 to measure associations but not proper causal effects of poverty in
38 mortality.
39
40
41
42
43
44
45

46
47 **Acknowledgements:** We are grateful to Alberto Palloni and the Health
48 Inequality reading group at LCDS for comments on earlier versions of
49 the manuscript, and to Monica Alexander and Ameer Dharamshi for
50 sharing their code related to reference 14. We thank the two
51 reviewers for their careful reading of the paper and
52 comments/suggestions that helped improve the paper.
53
54

55
56 **Funding:** JMA acknowledges support by European Union Horizon 2020
57 research and innovation programme under the Marie Skłodowska-Curie
58 grant agreement No 896821, ROCKWOOL Foundation's grant on excess
59 deaths, and the Leverhulme Trust Centre grant.
60

1
2
3
4 **Data availability statement:** This analysis used publicly available
5 data. All data are available at <https://doi.org/10.5281/zenodo.6797737>
6 and scripts generating results are available at
7 <http://www.github.com/gomena/life-expectancy-chile>.
8
9

10
11 **Author contributions:** GM: data curation, software, validation; GM
12 and JMA: formal analysis, investigation, conceptualisation,
13 methodology, project administration, resources, validation,
14 visualisation, writing (original draft), and writing (review &
15 editing).
16
17

18 **Ethics approval:** This research project does not require ethics
19 approval as it uses only macro data that are freely available
20 online.
21
22

23 **Conflict of interest:** None declared.
24
25

26 27 **References**

- 28
29 1. World Health Organization. *The World health report : 2000 : Health systems : improving*
30 *performance*. (World Health Organization, 2000).
31
32
- 33 2. Alvarez, J.-A., Aburto, J. M. & Canudas-Romo, V. Latin American convergence and
34 divergence towards the mortality profiles of developed countries. *Population Studies* **74**,
35 75–92 (2020).
36
37
- 38 3. Castanheira, H. C., Costa Monteiro da Silva, J. H., Del Popolo, F., Guiomar, B. & Saad,
39 P. COVID-19 mortality. Evidence and scenarios. *Latin American and Caribbean*
40 *Demographic Centre (CELADE)-Population Division of ECLAC, United Nations* (2021).
41
42
- 43 4. Sullivan, M. & Myer, P. Latin America and the Caribbean: Impact of COVID-19.
44 <https://crsreports.congress.gov/product/details?prodcode=IF11581>.
45
46
- 47 5. Aburto, J. M. *et al.* Quantifying impacts of the COVID-19 pandemic through life-
48 expectancy losses: a population-level study of 29 countries. *International Journal of*
49 *Epidemiology* (2021) doi:10.1093/ije/dyab207.
50
51
- 52 6. Mena, G. E. *et al.* Socioeconomic status determines COVID-19 incidence and related
53 mortality in Santiago, Chile. *Science* (2021) doi:10.1126/science.abg5298.
54
55
56
57
58
59
60

- 1
2
3 7. Millalen, P., Nahuelpan, H., Hofflinger, A. & Martinez, E. COVID-19 and Indigenous
4 peoples in Chile: vulnerability to contagion and mortality. *AlterNative: An International*
5 *Journal of Indigenous Peoples* **16**, 399–402 (2020).
6
7
- 8
9 8. Lima, E. E. C. *et al.* Investigating regional excess mortality during 2020 COVID-19
10 pandemic in selected Latin American countries. *Genus* **77**, 30 (2021).
11
12
- 13 9. Cifuentes, M. P., Rodriguez-Villamizar, L. A., Rojas-Botero, M. L., Alvarez-Moreno, C. A.
14 & Fernández-Niño, J. A. Socioeconomic inequalities associated with mortality for
15 COVID-19 in Colombia: a cohort nationwide study. *J Epidemiol Community Health* **75**,
16 610–615 (2021).
17
18
- 19 10. Castro, M. C. *et al.* Reduction in life expectancy in Brazil after COVID-19. *Nat Med* 1–7
20 (2021) doi:10.1038/s41591-021-01437-z.
21
22
- 23 11. Schoeley, J. *et al.* Bounce backs amid continued losses: Life expectancy changes since
24 COVID-19. 2022.02.23.22271380 Preprint at
25 <https://doi.org/10.1101/2022.02.23.22271380> (2022).
26
27
- 28 12. Aburto, J. M., Schöley, J., Kashnitsky, I. & Kashyap, R. Life expectancy declines in
29 Russia during the COVID-19 pandemic in 2020. Preprint at
30 <https://doi.org/10.31219/osf.io/7cuvy> (2021).
31
32
- 33 13. Bilal, U. *et al.* Inequalities in life expectancy in six large Latin American cities from the
34 SALURBAL study: an ecological analysis. *The Lancet Planetary Health* **3**, e503–e510
35 (2019).
36
37
- 38 14. Alexander, M., Zagheni, E. & Barbieri, M. A Flexible Bayesian Model for Estimating
39 Subnational Mortality. *Demography* **54**, 2025–2041 (2017).
40
41
- 42 15. Departamento de Estadísticas Vitales. Departamento de Estadísticas e Información de
43 Salud. <https://deis.minsal.cl/>.
44
45
- 46 16. Instituto Nacional de Estadísticas de Chile. Instituto Nacional de Estadísticas de Chile.
47 <https://redatam-ine.ine.cl/>.
48
49
- 50 17. INE. Proyecciones de Población. *Default*
51 <http://www.ine.cl/estadisticas/sociales/demografia-y-vitales/proyecciones-de-poblacion>.
52
53
54
55
56
57
58
59
60

- 1
2
3 18. Preston, S. H., Heuveline, P. & Guillot, M. *Demography, Measuring and Modeling*
4 *Population Processes*. (Wiley Blackwell, 2001).
5
6
7 19. Berdegué, J., Jara, E., Modrego, F., Sanclemente, X. & Schejtman, A. *Ciudades rurales*
8 *de Chile. Working papers* <https://ideas.repec.org/p/rms/wpaper/061.html> (2010).
9
10
11 20. Ministerio de Desarrollo Social. Observatorio Social - Ministerio de Desarrollo Social y
12 Familia. <http://observatorio.ministeriodesarrollosocial.gob.cl/encuesta-casen>.
13
14
15 [dataset] 21. Mena, G. & Aburto, J. Data from: The unequal impact of the COVID-19
16 pandemic in 2020 on life expectancy across urban areas in Chile: A cross-sectional
17 demographic study.
18
19
20
21
22 22. Gelman, A., Carlin, J. B., Stern, H. S. & Rubin, D. B. *Bayesian Data Analysis*. (Chapman
23 and Hall/CRC, 1995). doi:10.1201/9780429258411.
24
25
26 23. Arriaga, E. E. Measuring and Explaining the Change in Life Expectancies. *Demography*
27 **21**, 83–96 (1984).
28
29
30 24. Gini, C. Measurement of Inequality of Incomes. *The Economic Journal* **31**, 124–126
31 (1921).
32
33
34 25. Bilal, U., Alfaro, T. & Vives, A. COVID-19 and the worsening of health inequities in
35 Santiago, Chile. *Int J Epidemiol* dyab007 (2021) doi:10.1093/ije/dyab007.
36
37
38 26. Edwards, R. D. The cost of uncertain life span. *J Popul Econ* **26**, 1485–1522 (2013).
39
40
41 27. Levin, A. T. *et al.* Assessing the age specificity of infection fatality rates for COVID-19:
42 systematic review, meta-analysis, and public policy implications. *Eur J Epidemiol* **35**,
43 1123–1138 (2020).
44
45
46 28. Aburto, J. M. *et al.* Quantifying impacts of the COVID-19 pandemic through life
47 expectancy losses. *medRxiv* 2021.03.02.21252772 (2021)
48
49
50
51
52
53
54 29. Miller, S., Wherry, L. R. & Mazumder, B. Estimated Mortality Increases During The
55 COVID-19 Pandemic By Socioeconomic Status, Race, And Ethnicity: Study examines
56 COVID-19 mortality by socioeconomic status, race, and ethnicity. *Health Affairs* **40**,
57 1252–1260 (2021).
58
59
60

- 1
2
3 30. Sanchez-Romero, M., Lee, R. D. & Prskawetz, A. Redistributive effects of different
4 pension systems when longevity varies by socioeconomic status. *The Journal of the*
5 *Economics of Ageing* **17**, 100259 (2020).
6
7
8
9 31. Auerbach, A. J. *et al.* How the Growing Gap in Life Expectancy May Affect Retirement
10 Benefits and Reforms. *Geneva Pap Risk Insur Issues Pract* **42**, 475–499 (2017).
11
12
13 32. Ward, Z. J. *et al.* Estimating the impact of the COVID-19 pandemic on diagnosis and
14 survival of five cancers in Chile from 2020 to 2030: a simulation-based analysis. *The*
15 *Lancet Oncology* **0**, (2021).
16
17
18
19 33. Bambra, C., Riordan, R., Ford, J. & Matthews, F. The COVID-19 pandemic and health
20 inequalities. *J Epidemiol Community Health* **74**, 964–968 (2020).
21
22
23
24 34. Palloni, A., Beltrán-Sánchez, H. & Pinto, G. Estimation of older-adult mortality from
25 information distorted by systematic age misreporting. *Population Studies* **0**, 1–18 (2021).
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 **Figure legends:**
4

5
6 **Figure 1**

7 Life expectancy at birth by sex and condition of Urban and Non-urban
8 in Chile. Notes: Solid lines correspond to estimates based on the
9 entire population on each group, with bands indicating 95% credible
10 regions.
11

12
13 **Figure 2**

14 Probabilitiy of not surviving to 65 years by sex and condition of
15 Urban and Non-urban in Chile. Notes: Solid lines correspond to
16 estimates based on the entire population on each group, with bands
17 indicating 95% credible regions.
18

19
20 **Figure 3**

21 Time evolution (2002 to 2020 period) of the heterogeneity in life
22 expectancy at birth (left), between 20 and 65 years (center) and at
23 65 years (right). **A** histograms of life expectancies over time, for
24 male/female and urban/non-urban divisions. **B** Time evolution of Gini
25 of the corresponding histograms in **A**. **C** Relative yearly changes in
26 the Gini's with respect to previous years. Bars represent 95%
27 credible intervals in B and C.
28
29

30
31
32 **Figure 4**

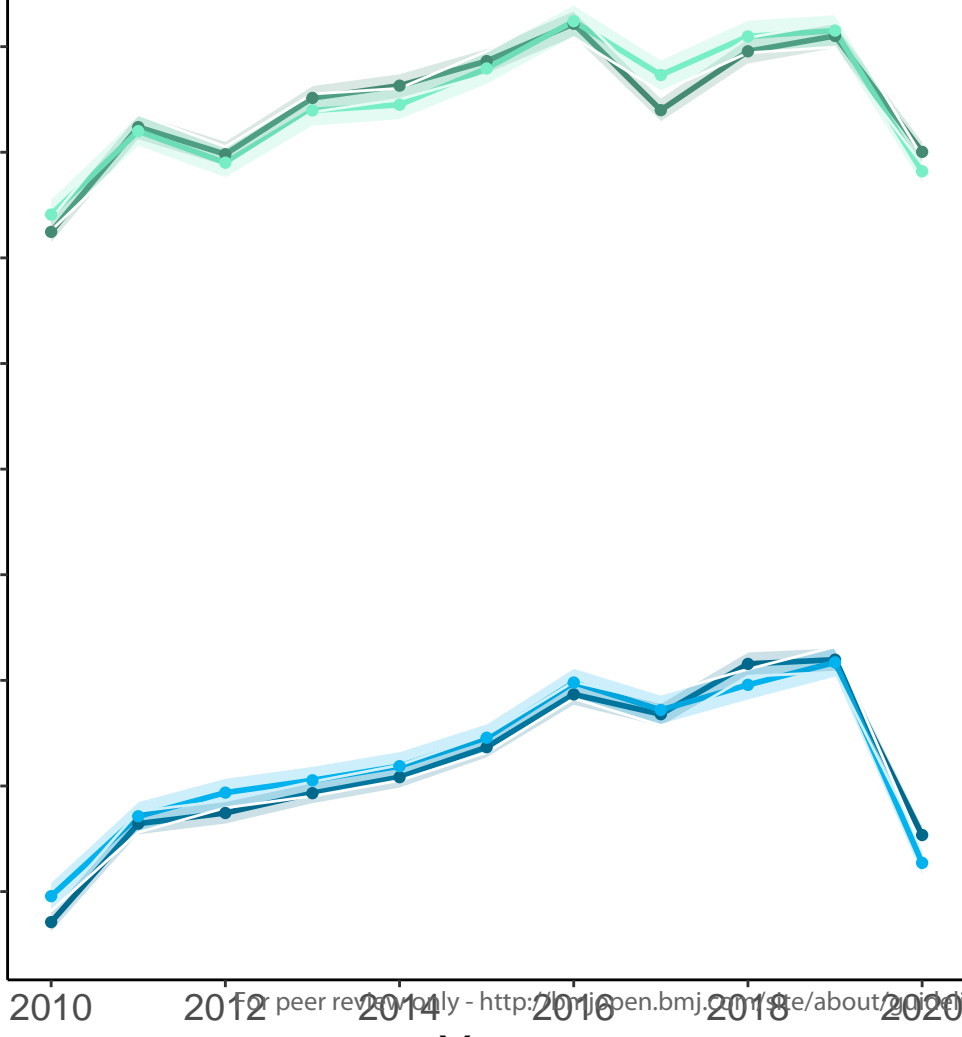
33 Changes in inequality of mortality in 2020 with respect to recent
34 history were stronger in younger age groups. A Comparison between
35 2015-2019 and 2020 of the average years lived between 20 and 65, for
36 males and females, as a function of poverty. B same as in A, but
37 with life expectancy at 65.
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

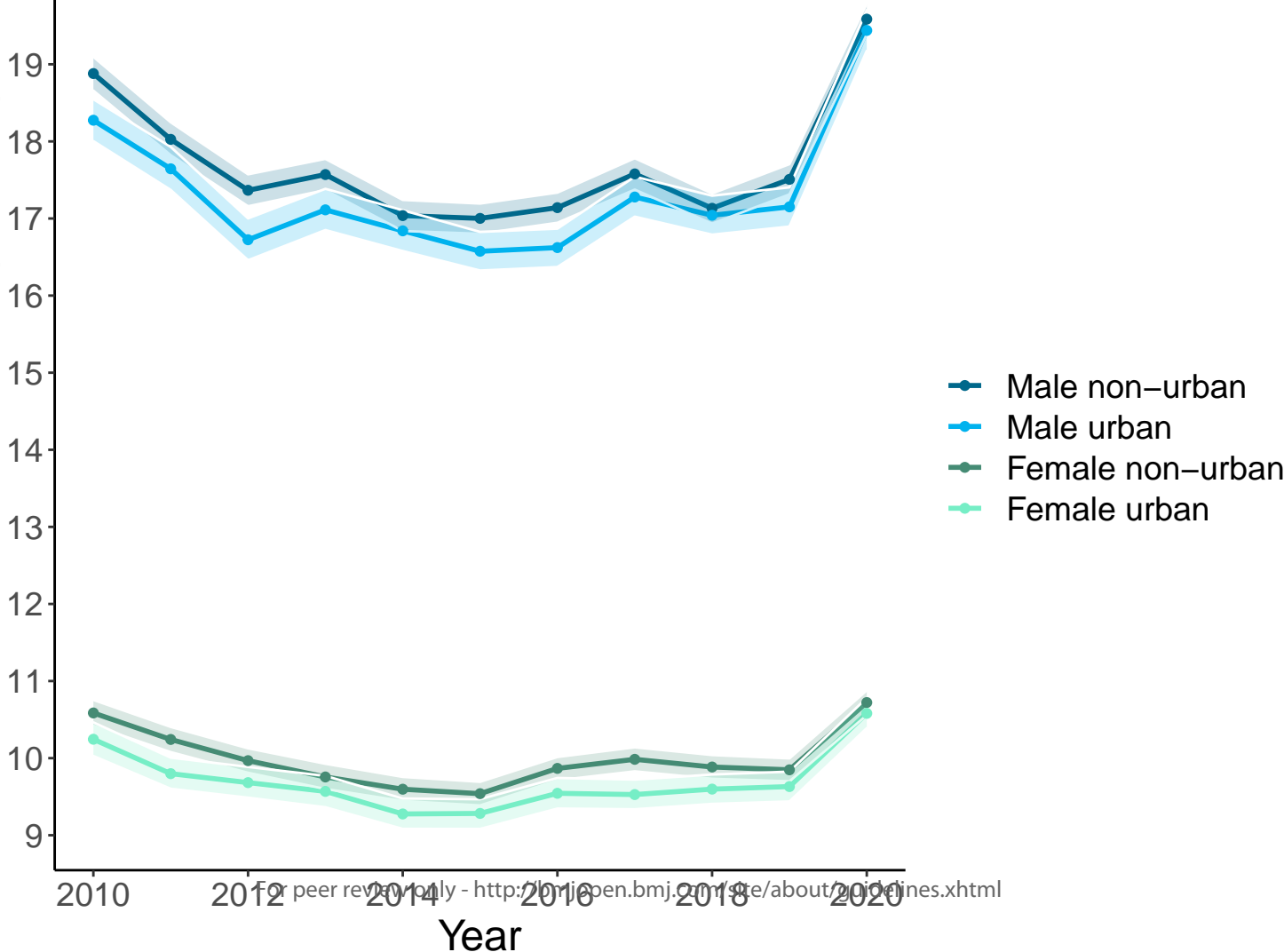
For peer review only

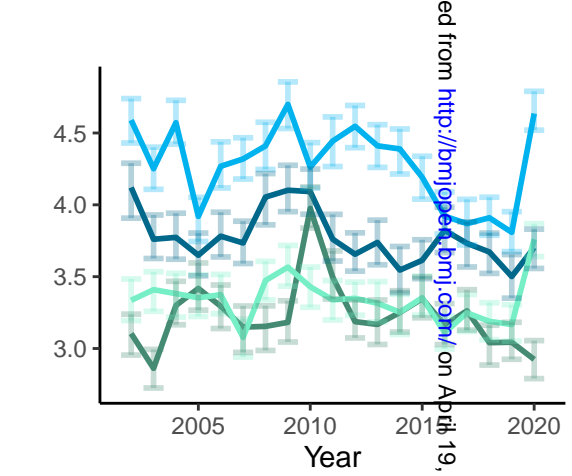
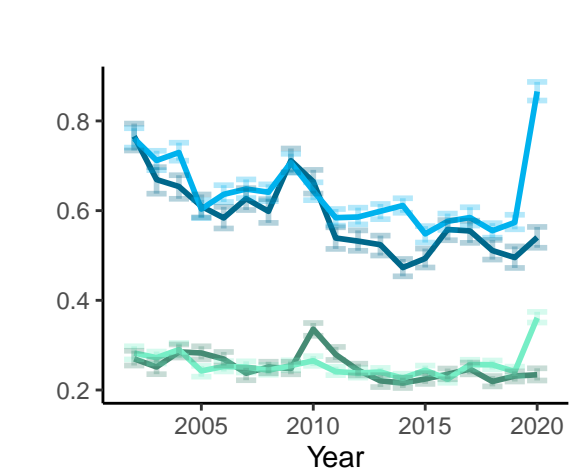
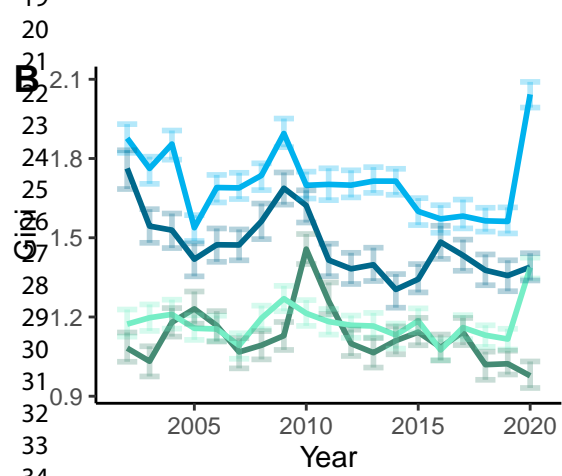
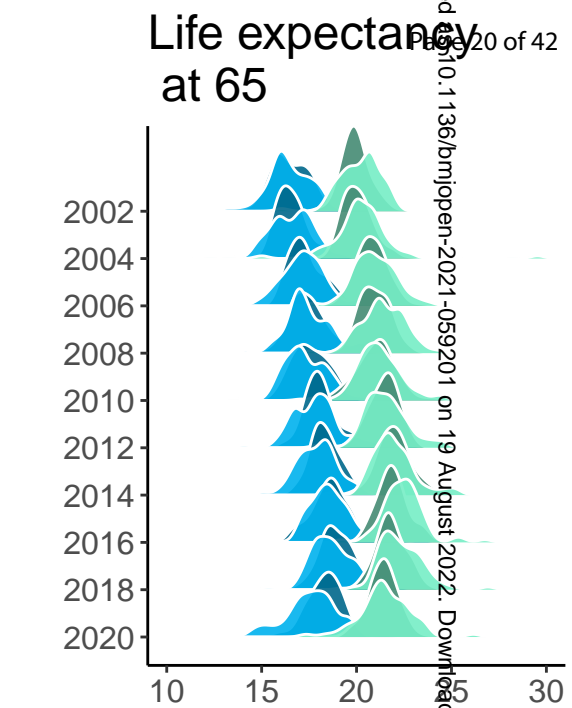
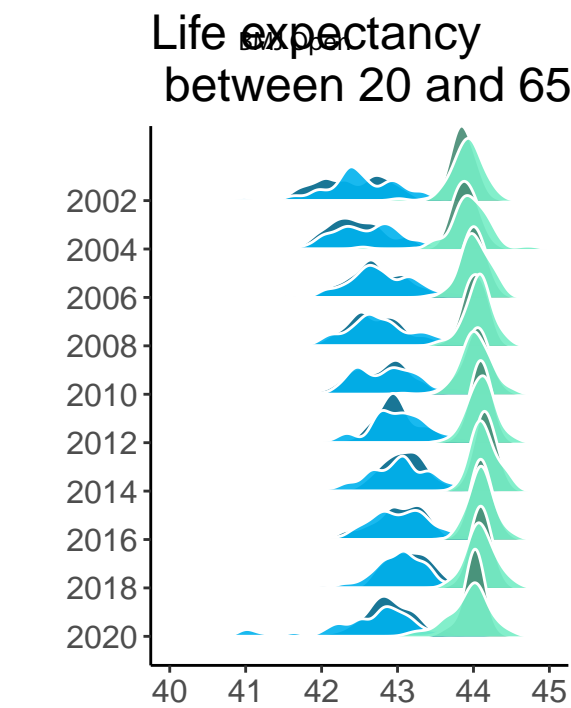
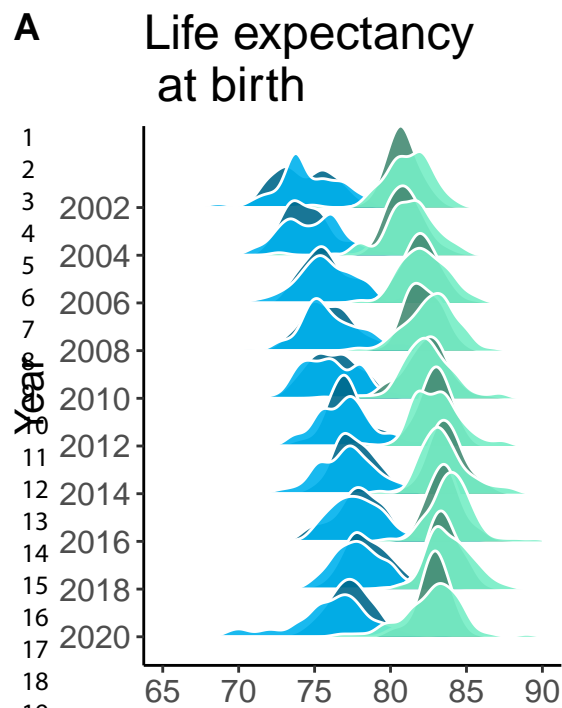
BMJ Open

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

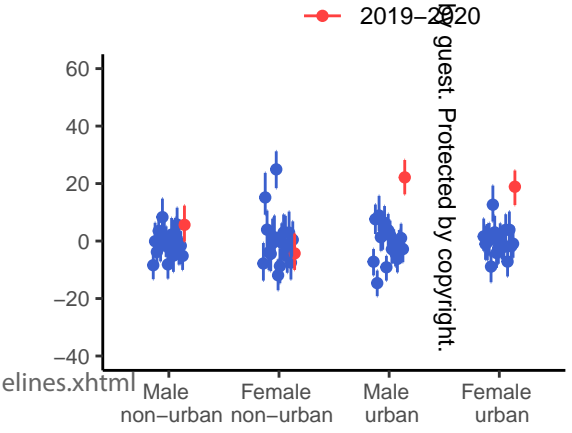
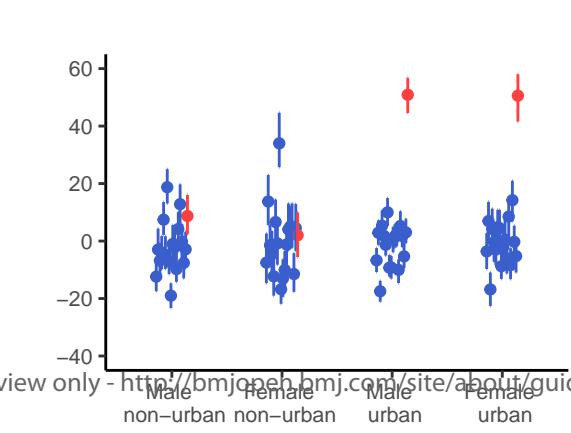
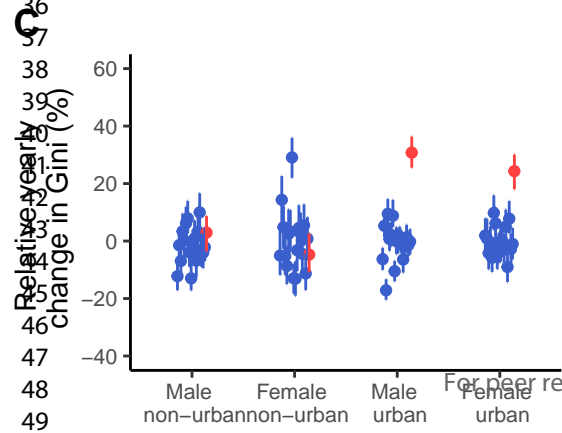


28
29
30
31
32



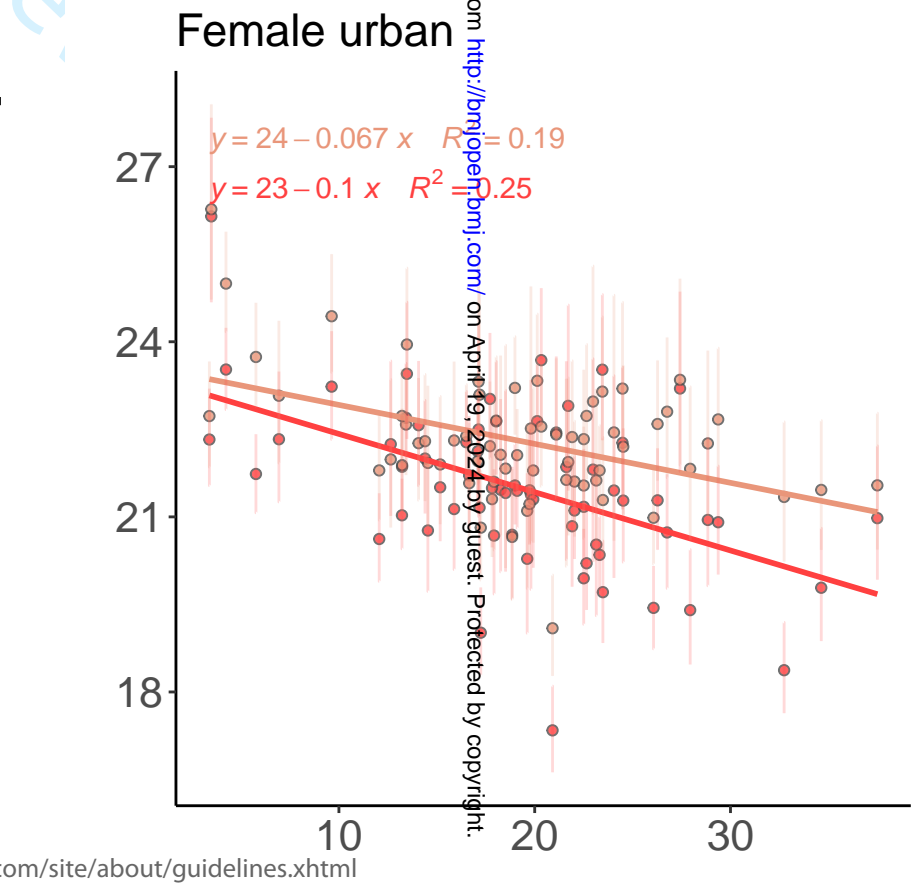
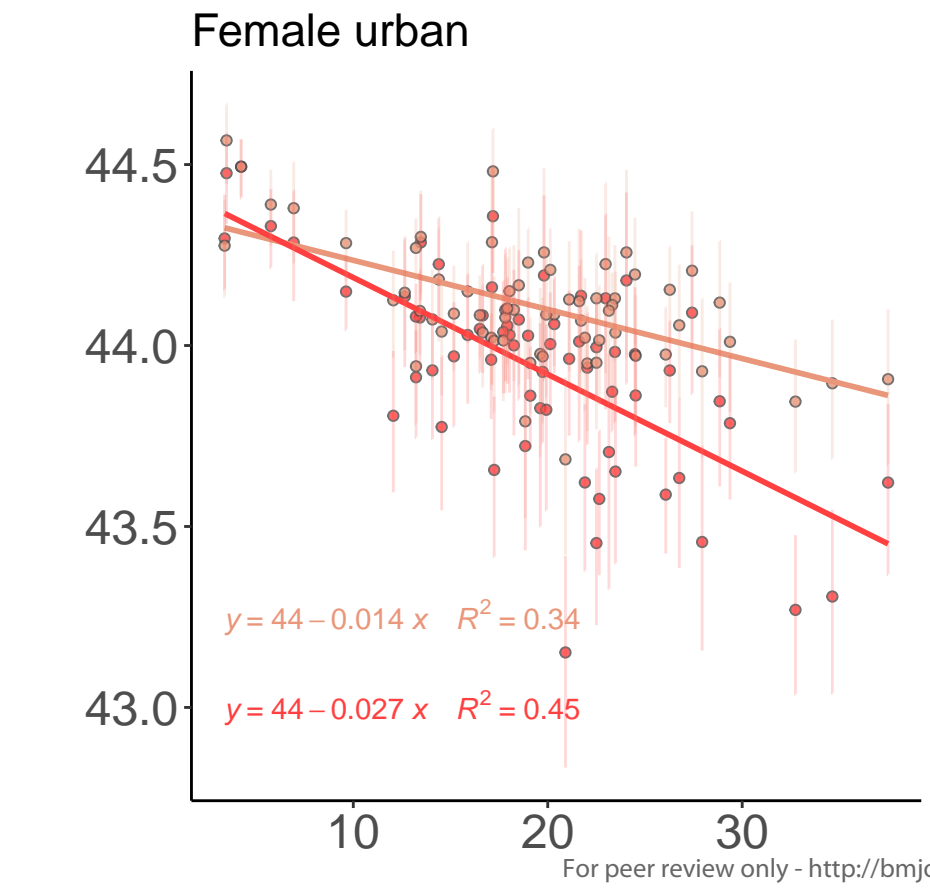
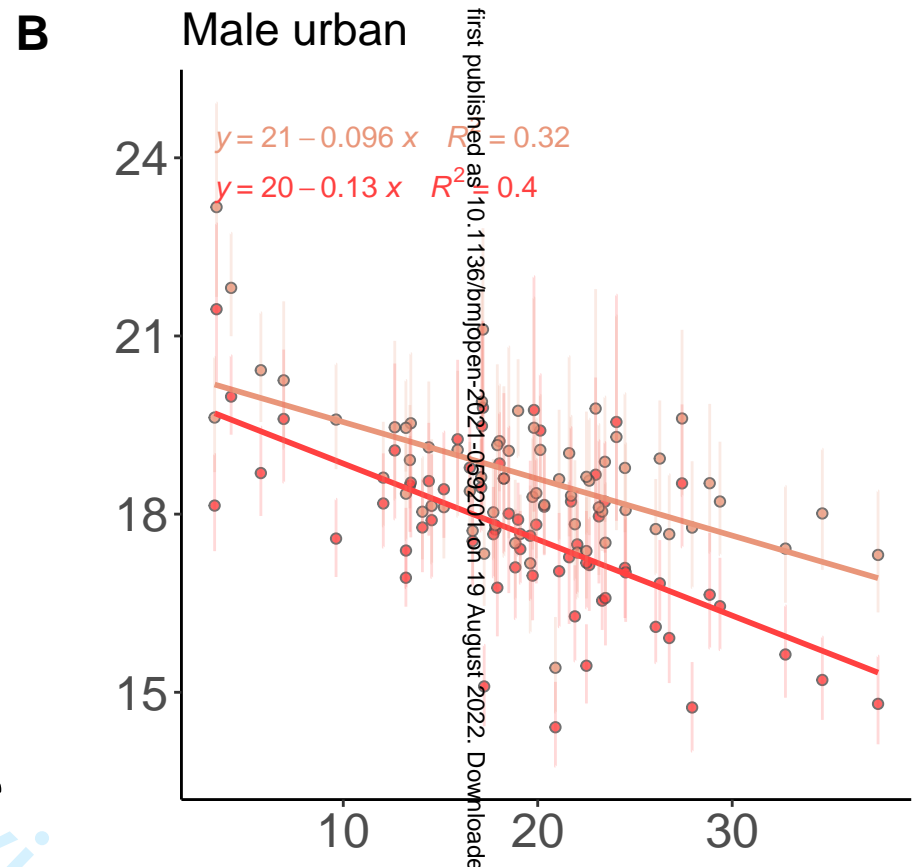
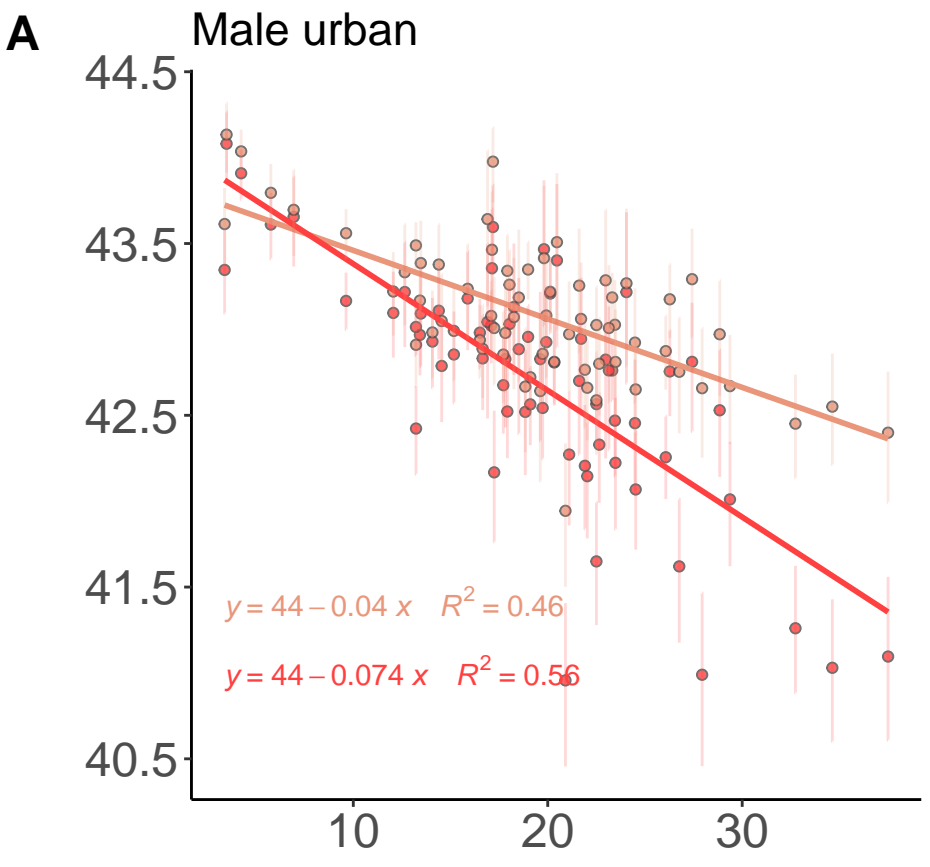


Male non-urban Male urban Female non-urban Female urban



2015–2019 2020

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



Poverty (%)

BMJ Open: first published as 10.1136/bmjopen-2021-029201 on 19 August 2022. Downloaded from <http://bmjopen.bmj.com/> on April 19, 2024 by guest. Protected by copyright.

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

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 were 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.

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.

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

1
2
3
4
5
6 more, this is an indication that official projections are not accurate, as they become inconsistent
7
8 in 2017 (i.e., official projections in year 2017 are far from official census in the same year).
9

10 **Main results with alternative estimates** In the main text we have used the cohort survival
11 projection method. Here, we present results using the other two alternative methods. Figs. 5
12 and 6 correspond to Exhibits 1 and 2 in the main text, respectively. Figs. 7 and 8 complement
13 Exhibit 3, and likewise, Figs. 9 and 10 complement Exhibit 4.
14
15
16
17
18

19 **5 Additional results**

20
21
22 Fig.11 supplements Exhibit 4 by showing the relation between life expectancy and poverty in
23 non-urban municipalities. No clear consistent pattern is observed. Also, in Fig. 12 we show
24 the corresponding decreases of life expectancy over time as a function of poverty, in urban
25 and non-urban setups. This figure is complemented by Fig. 13, which shows an even stronger
26 correlation when using crowdedness as covariate, and Figs. 14 and 15, which show sensitivity
27 of Fig. 12 to changes in the projection methodology.
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

	Urban	Rural	Excluded	Total
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. Berdegúe, 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].).

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.

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, Vallendar, 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, 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
Valparaíso	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
O'Higgins	Talca, Curico, Constitucion, Maule, San Clemente, Cauquenes, Molina, Sagrada Familia, Teno, Linares, Colbun, Longavi, Parral, Retiro, San Javier, Villa Alegre, Yervas Buenas
Maule	Curepto, Empedrado, Pelarco, Penciahue, 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, 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
Metropolitana	Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquin, San Miguel, San Ramon, Vitacura, Puente Alto, San Bernardo, Padre Hurtado, Penaflo, Pirque, San Jose de Maipo, Colina, Lampa, Tiltill, 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.

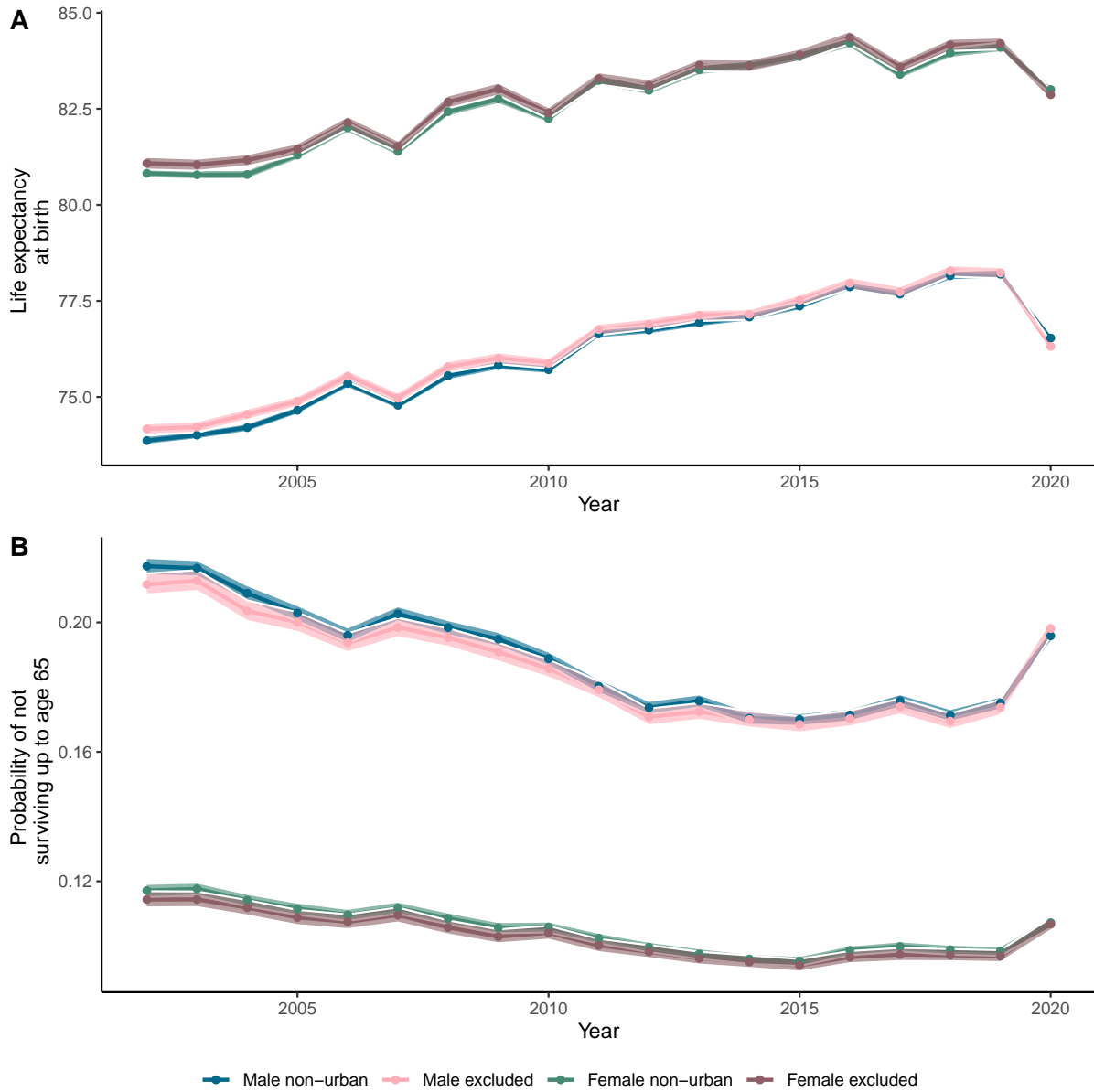


Figure 1: **A.** Time evolution of life expectancy, including the excluded municipalities collapsed as a super-municipality. **B.** Same as **A**, but with likelihood of dying before reaching 65.

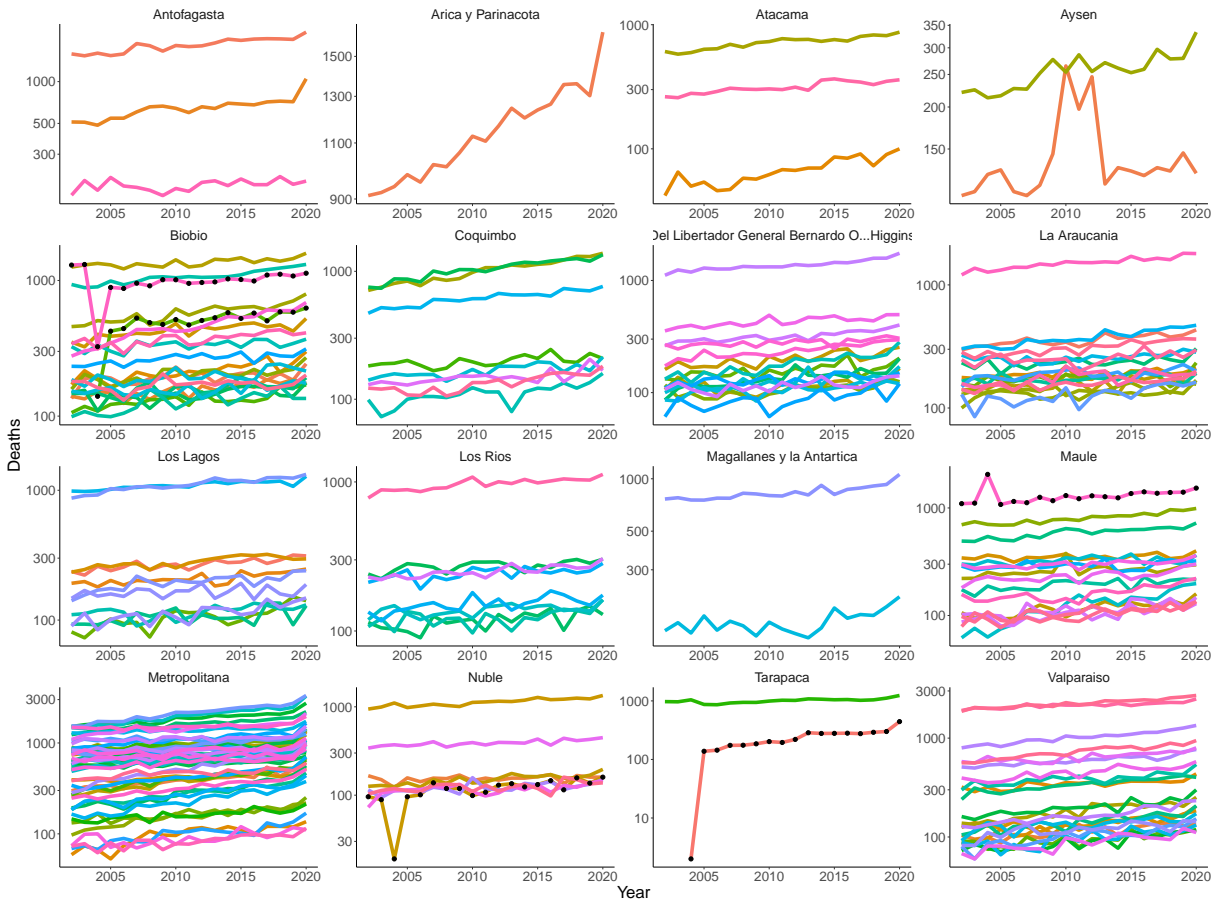


Figure 2: Yearly deaths for each municipality (colored lines) grouped by region (different plots). Lines that are also dotted are the ones for which anomalies existed in recording, leading to sudden drops and/or increases around 2004, presumably due to coding errors. These were excluded in the neighboring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

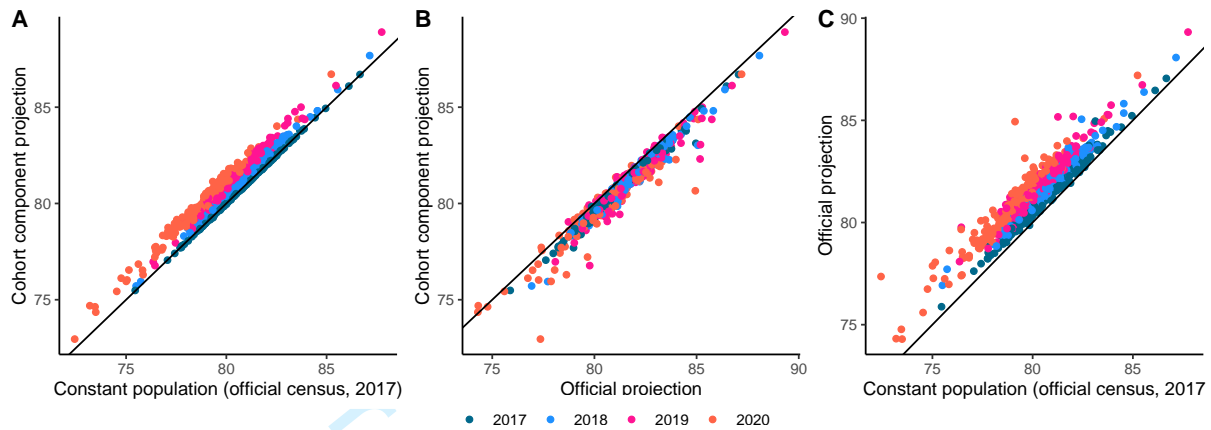


Figure 3: Comparison of various life expectancy estimates, for years 2017-2020. All of these use 80 as cutoff age for population counts. In **A** we compare cohort survival projection with the one that makes the population constant from 2017 on. In **B** we compare official projections with cohort survival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

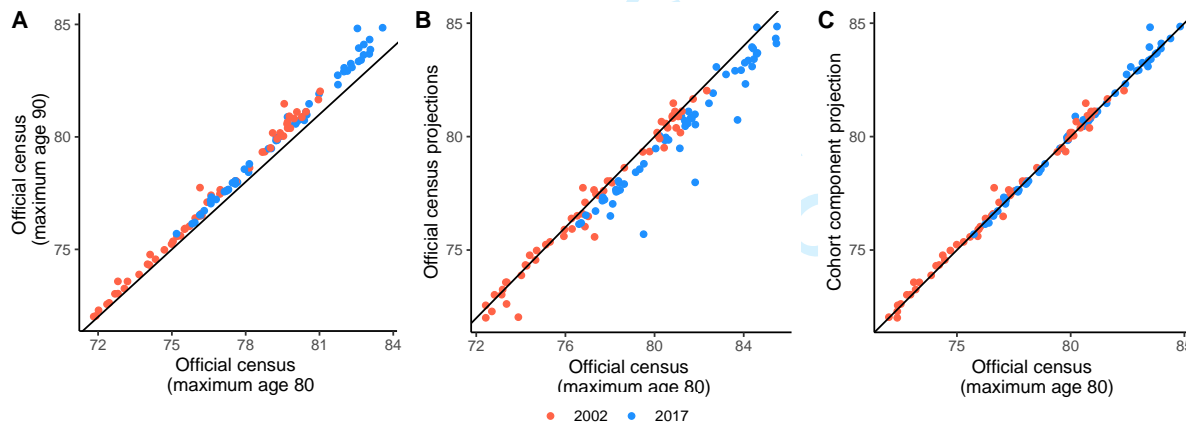


Figure 4: Comparison of several life expectancy estimates, only for census years (2002, 2017). In **A** we compare estimates based on census data but different age cutoffs. When using 90 as cutoff, life expectancies appear slightly higher. In **B** we compare the official census data with 80 cutoff with 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.

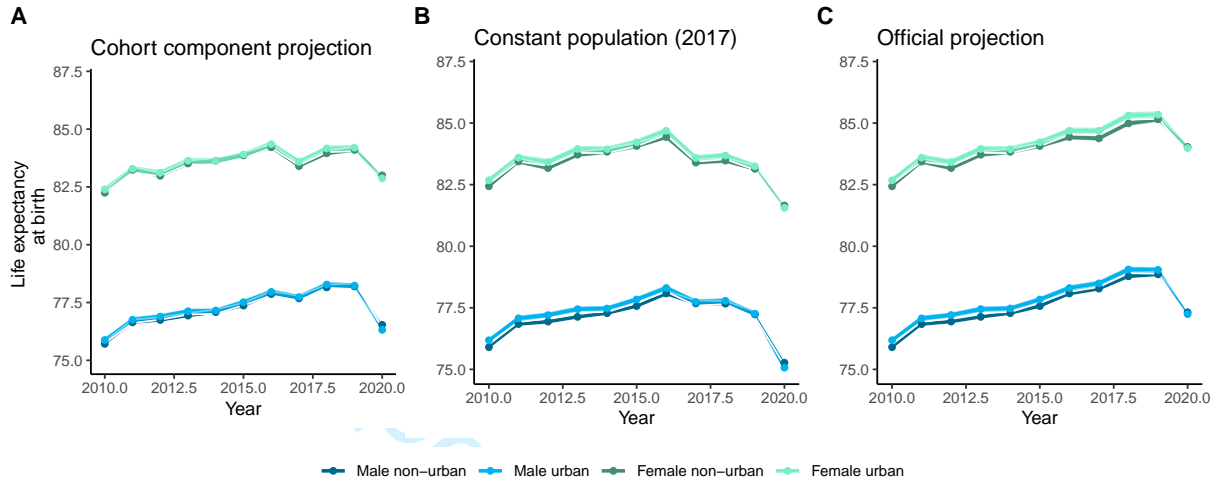


Figure 5: Time evolution of life expectancy, using our three estimators, Exhibit 1 in main text coincides with A.

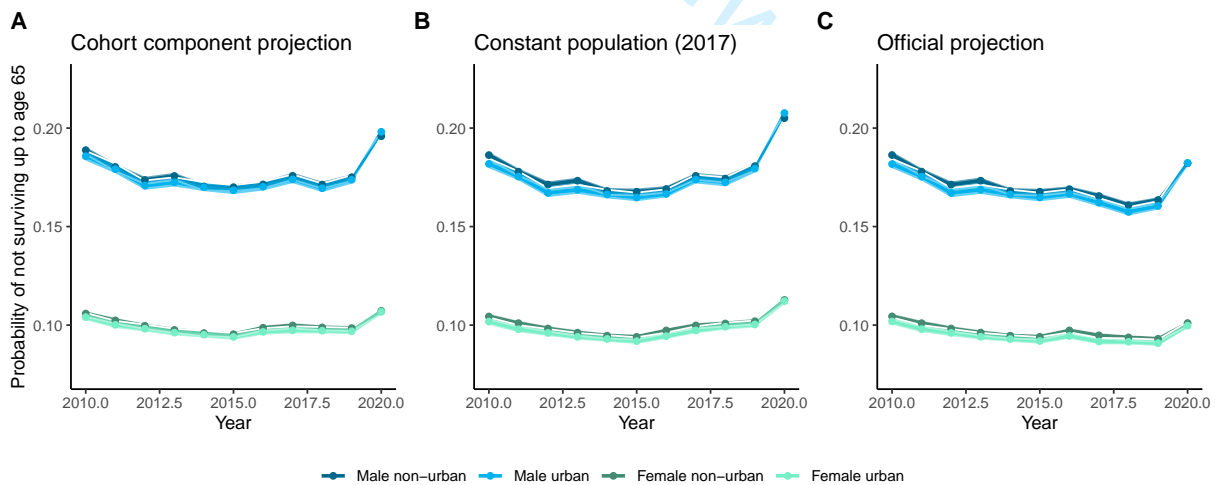


Figure 6: Time evolution probability of not surviving up to 65 years, using our three estimators. Exhibit 2 in main text coincides with A.

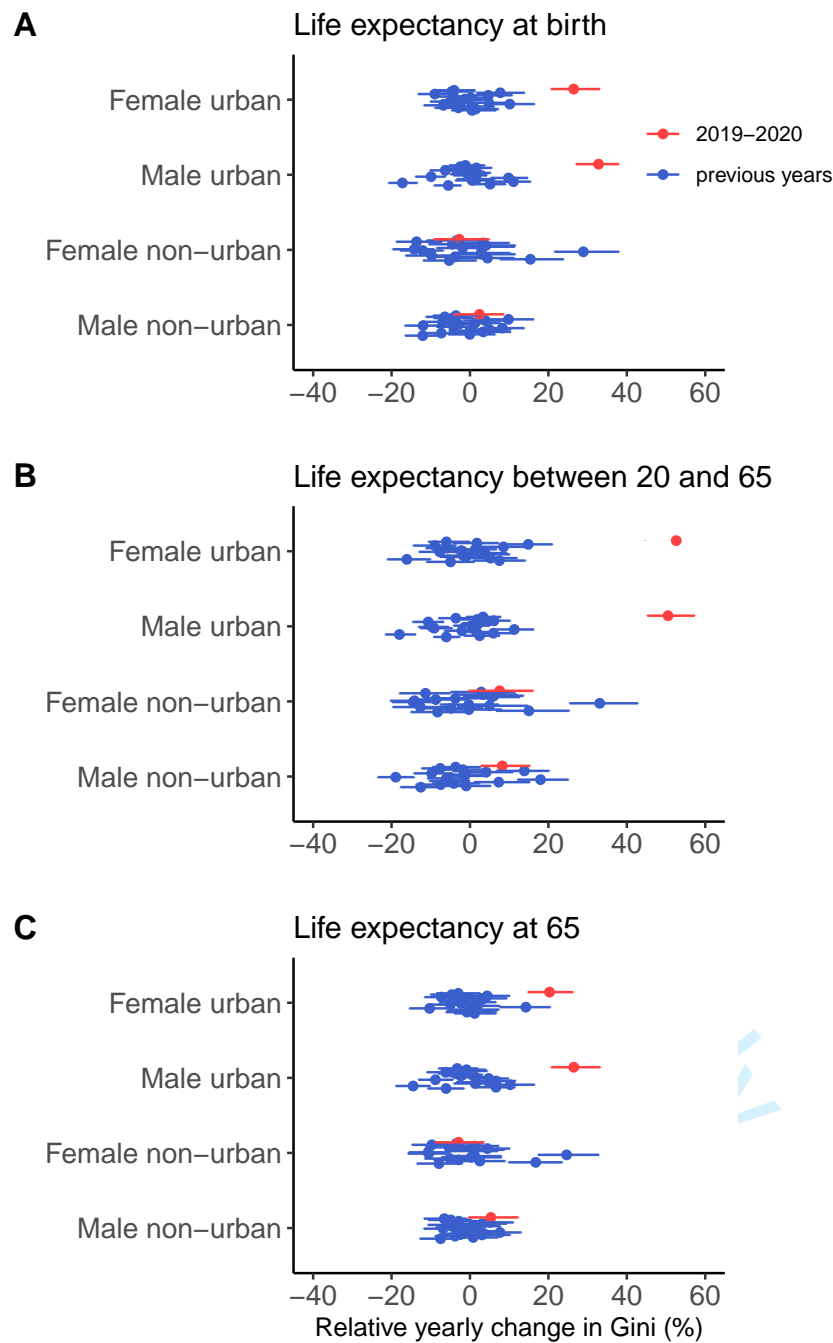


Figure 7: Year-to-year relative changes in Gini, where we have assumed that population after 2017 remained constant (equal to the one provided by census). Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

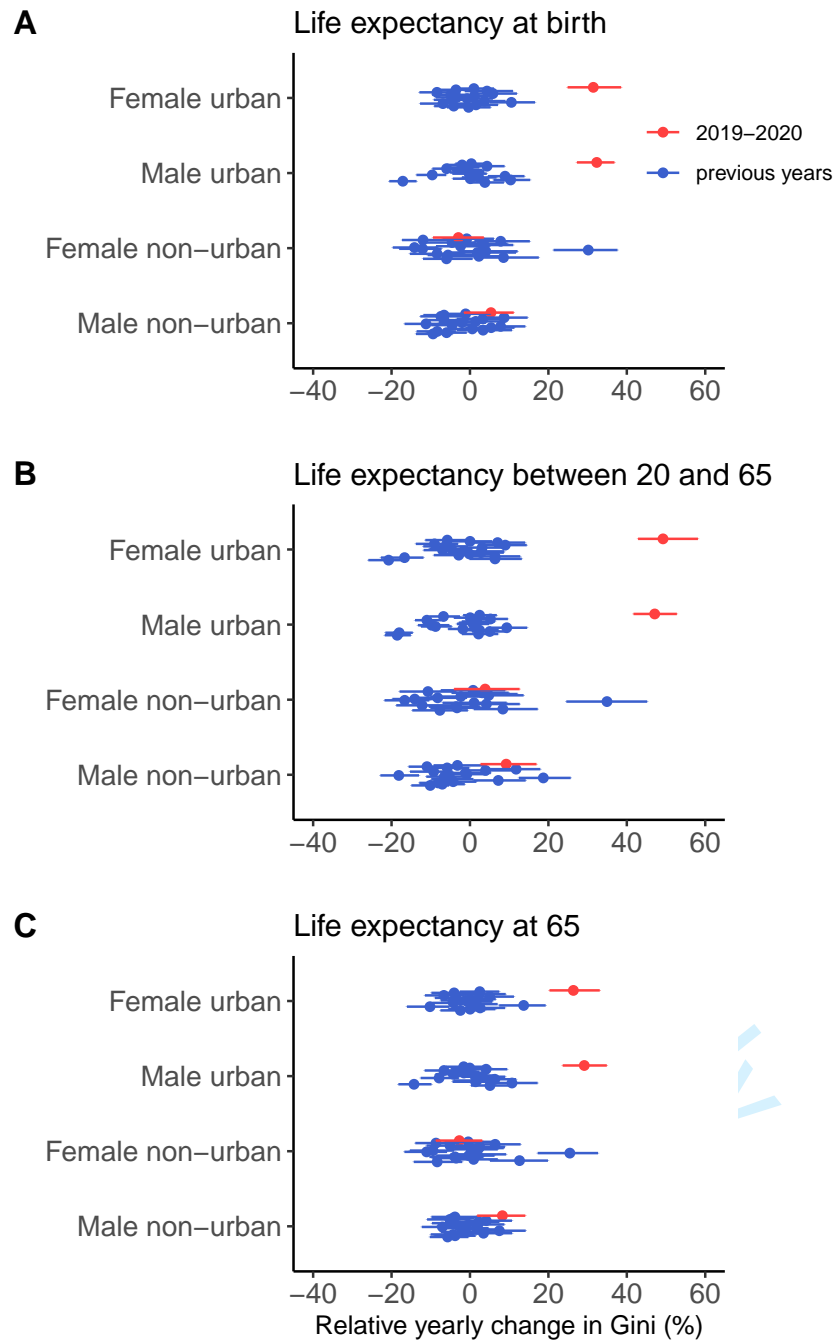


Figure 8: Year-to-year relative changes in Gini, where we have used the official census projections. Bars represent 75% credible intervals. This figure supplements Exhibit 3 in the main text.

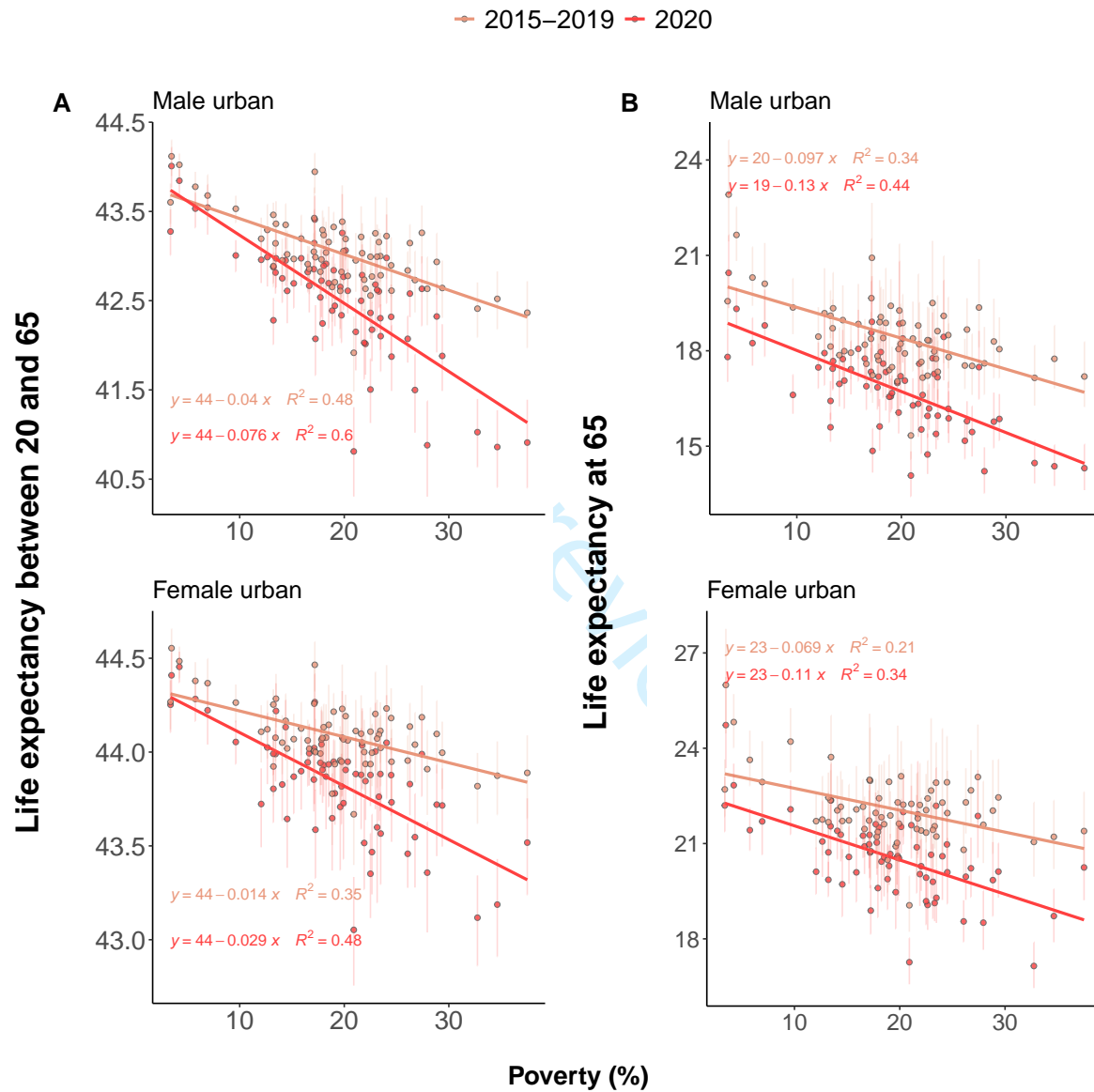


Figure 9: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. Bars represent 95% credible intervals. These estimates are based on the method that fixed population counts at values in 2017 for years 2017, 2018, 2019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

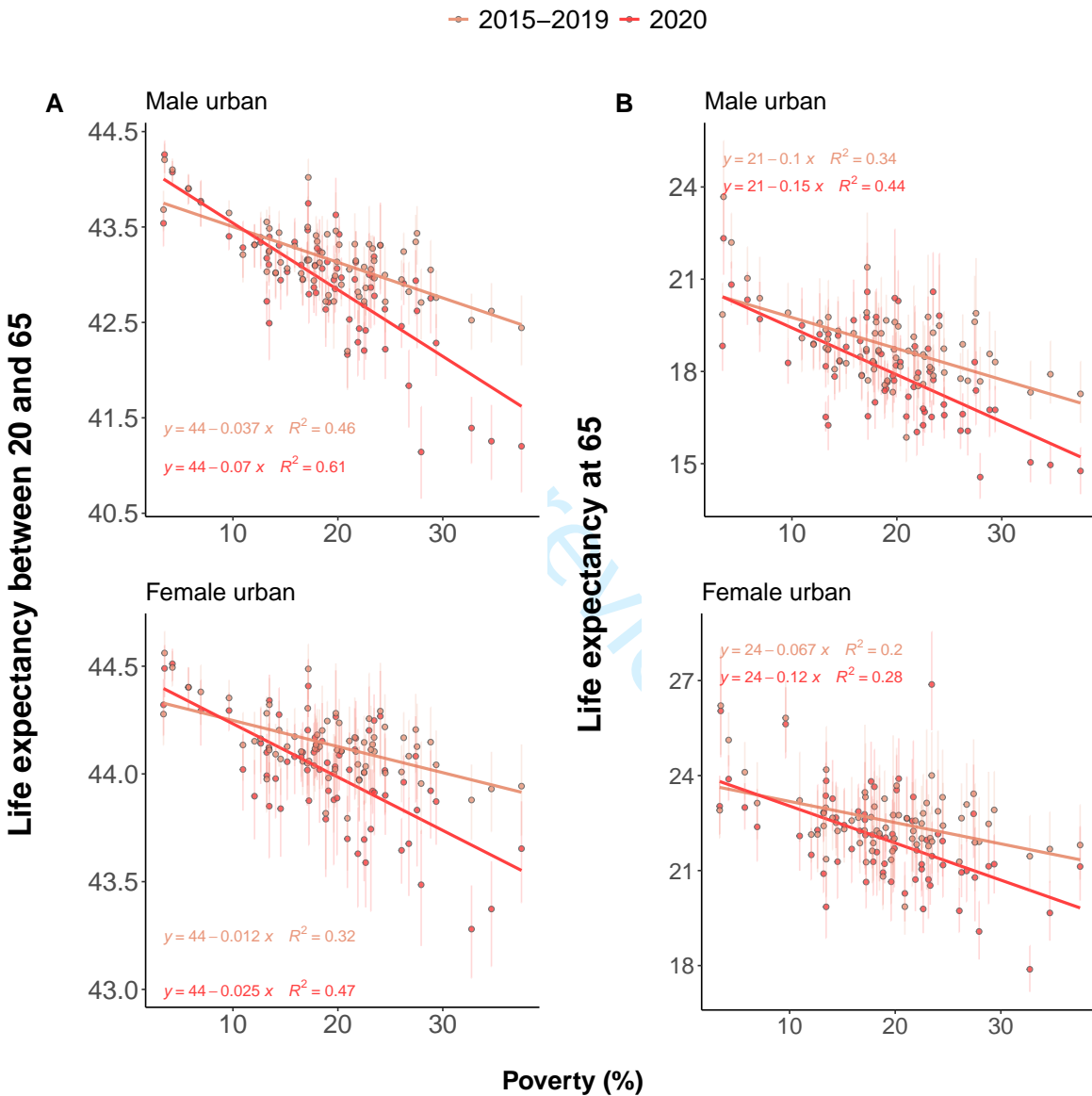


Figure 10: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for urban municipalities. These estimates are based on the official census projections and may be compared with Exhibit 4 in the main text.

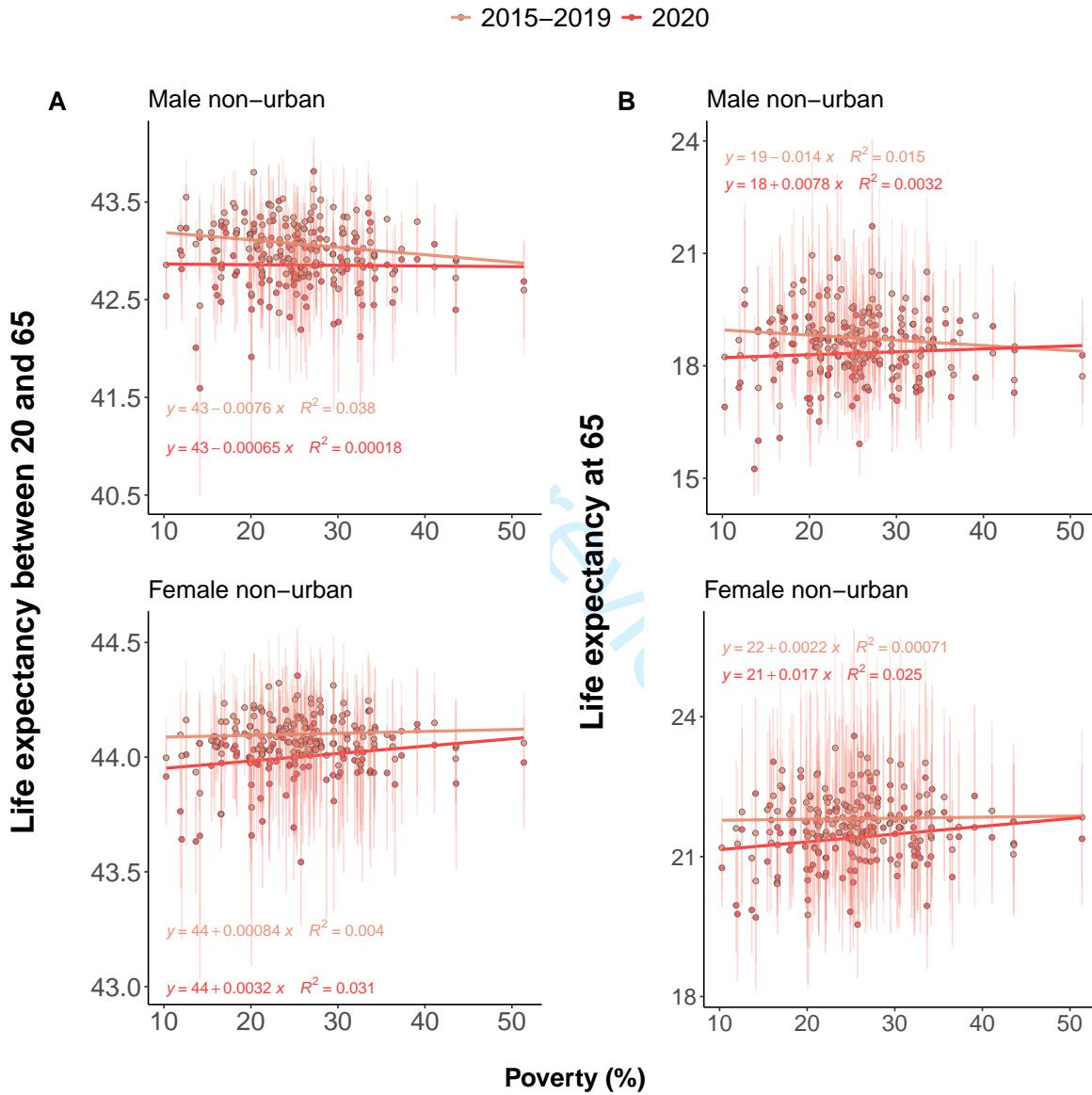


Figure 11: **A** Life expectancy between 20 and 65 and **B** and life expectancy at 65 as a function of poverty and gender, for non-urban municipalities. These are similar to results in Exhibit 4 in the main text, but correlations vanish when focusing on non-urban municipalities.

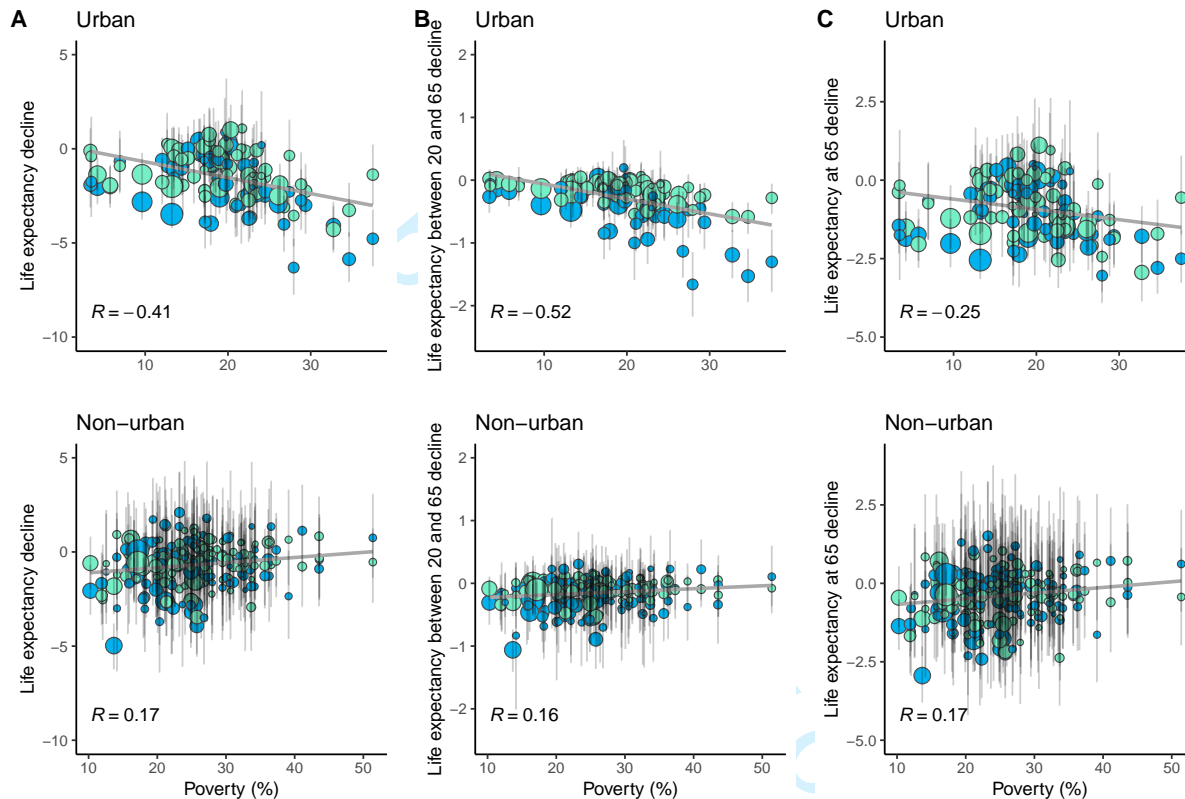
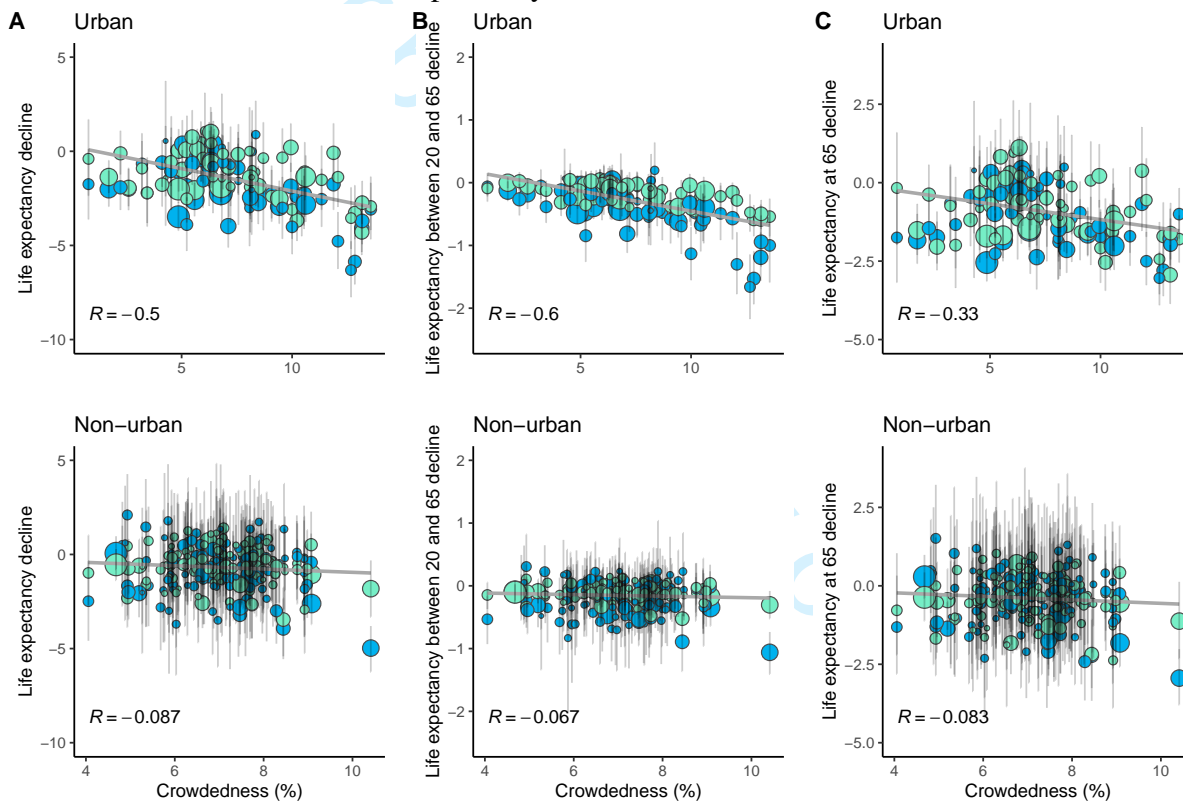


Figure 12: Declines in life expectancy at birth (A), life expectancy between 20 and 65 (B), and life expectancy at 65 (C) as a function of proportion of population that lives in poverty. Each dot is a municipality, separated by gender (colors) Urban and non-urban municipalities are shown in first and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

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.



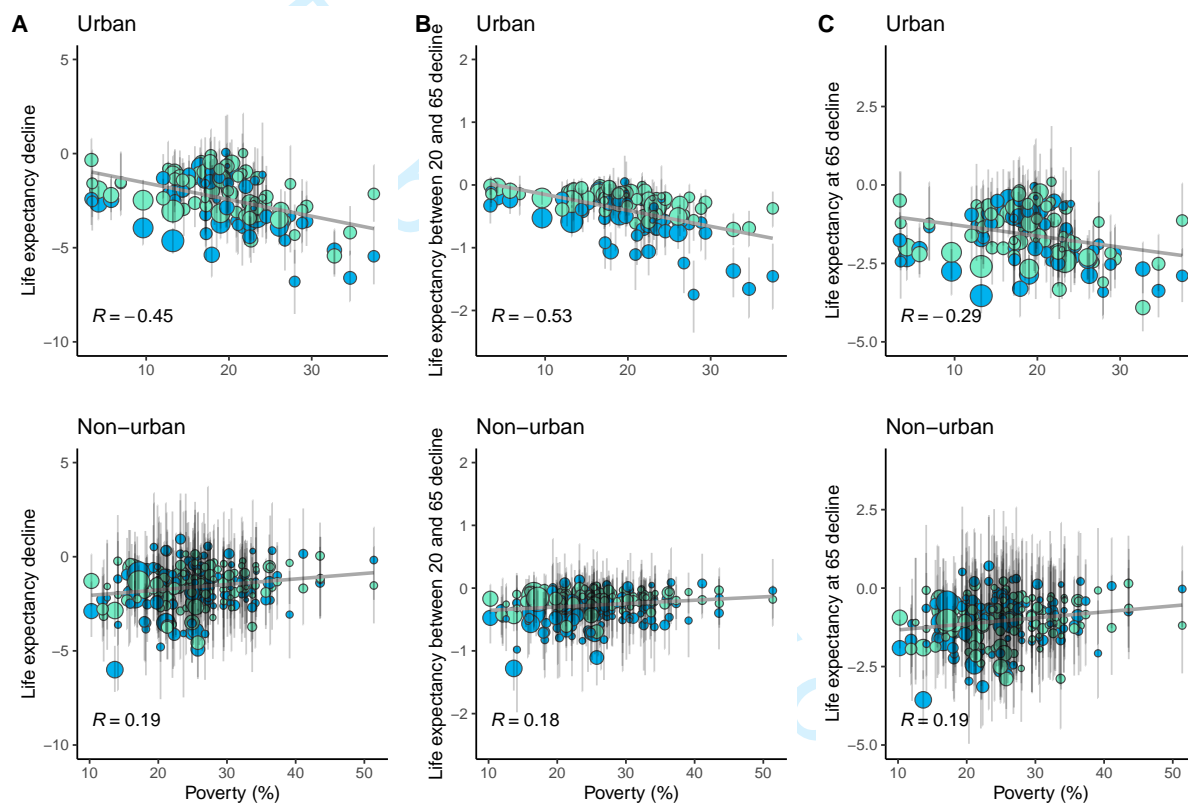


Figure 14: Same as 12 but with population estimates for years 2017,2018,2019,2020 all equal to population counts in 2017 as given by census.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

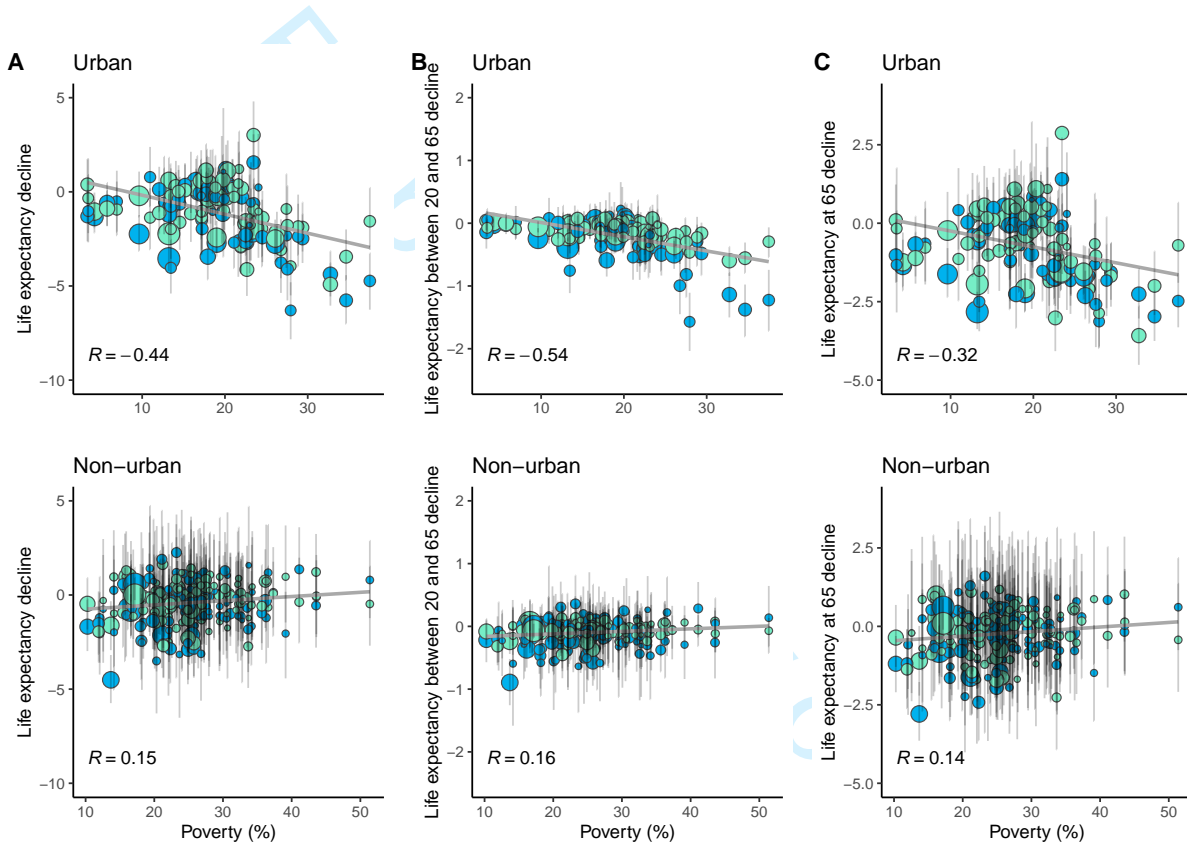


Figure 15: Same as 12 but with population estimates given by official projections.

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

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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.