Age Structure and Living Arrangements Shape the Vulnerability of Spanish Provinces to Outbreaks of Covid-19

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Background

Previous research has documented how age structures and co-residence patterns shape the vulnerability of populations to outbreaks of covid-19, with Spain being among the most vulnerable countries.

Objective

To document the role of age-specific co-residence patterns in shaping the vulnerability of Spanish provinces to mortality arising from within-household transmission of covid-19.

Method

We use data from the Spanish Population Registry 2018 on 10% of the population residing in private households in Spain. We combine information on the age and number of household members with infection fatality ratios related to covid-19 to estimate the average number of deaths per infection if a person becomes infected and transmits the virus to other household members.

Results

Children live in the largest households of all age groups on average. However, the age profile of the persons that children live with reduces, but does not eliminate, the risk of mortality arising due to within-household transmission of the virus.

Provinces with aged populations face a double challenge. Not only do they have large numbers of vulnerable persons due to their age, older persons are also more likely to share the same households in aged provinces.

Contribution

We show how the vulnerability of Spanish provinces to covid-19 varies due to age structure and co-residence patterns and document the role of specific age-based co-residence arrangements in this result.

Keywords: Population Characteristics; Family; Coronavirus Infections; Mortality; Demography

As the covid-19 pandemic is still evolving, researchers have started to document the factors that shape variation in mortality related to covid-19 across geographical areas. Predicting the development and consequences of the pandemic across areas would require accounting for a wide range of factors, including factors such as pre-existing morbidities, health systems, and social interaction. In this article, we focus on demographic factors that, all else equal, can shape the vulnerability of countries to mortality related to covid-19 (Dowd et al., 2020; Esteve et al., 2020a; Nepomuceno et al., 2020). Fatalities due to infection with the virus are heavily concentrated among older persons (Verity et al., 2020), and cross-country differences in death tolls across countries are related to the age-structure of countries' populations (Dowd et al., 2020). Co-residence patterns within households are likely to cause variation in the vulnerability of geographical areas to covid-19 (Esteve et al., 2020a). Indoor transmission has received increased attention after the confinement of people in their homes in many countries across the globe (Li et al., 2020; Qian et al., 2020).

Previous research on how age structure and co-residence patterns shape vulnerability of populations to covid-19 ranked Spain among the most vulnerable countries (Esteve et al., 2020a). These results were based on the 2011 census. Spain is a country with an aged population and a relatively high level of intergenerational co-residence (Moreno, 2012; Reher, 1998). Therefore, we ask the two following main questions: Which specific co-residence arrangements contribute to the vulnerability of the Spanish population overall? And how does vulnerability to covid-19 outbreaks vary across provinces in Spain?

We use data on household structure from population registries for the year 2018 and combine this information with estimates of Covid-19 infection fatality ratios to estimate

how variation in co-residence patterns shapes vulnerability to Covid-19. Describing co-residence patterns and related vulnerability is important for at least two reasons.

First of all, co-residence patterns differ by age and this has been central to discussions on age-specific confinement policies across countries. For instance, many countries have closed and opened schools, therewith exposing children (and those who they get into contact with) to possible infection. The extent to which such policies can have consequences for mortality depends, among other factors, on whether children live with persons who are vulnerable to dying from infection by covid-19. Ideally, infections should be prevented for vulnerable individuals and their co-residents by considering a large variety of characteristics (e.g. pre-existing medical conditions). However, many policies, including those discussed above, are applied to age groups without discrimination.

Secondly, co-residence patterns vary across geographical areas and this affects the vulnerability of these areas to deaths that can arise due to within-household transmission of the virus. To illustrate, in a fictive society where everyone lives alone, a “perfect” confinement policy will effectively reduce further transmissions. However, in a society where people live together the virus can still spread within households after a “perfect” confinement policy is implemented. Therefore, reductions in mortality will be delayed after confinement policies are implemented in areas where vulnerable persons share their residence with more people (all else equal).

Data and Method

We use Spanish registry data from the *Padrón Continuo de Habitantes* provided by the National Institute of Statistics (INE) including information on age and household structure for 10% of the Spanish population residing in private households in 2018. It is important to note that our data does not include persons living in collective households such as old-age homes. We select all 4,615,168 cases.

Besides describing the size and age-composition of households, the analysis is based on calculating the "vulnerability" of households to deaths arising from within-household transmission of covid-19. This indicator of vulnerability is based on the number and age of household members combined with age-specific infection fatality rates related to covid-19. More specifically, we calculate the estimated number of household members that dies after an individual becomes infected and transmits the virus to *all* other household members. To calculate this number we first create a variable indicating the number of persons each individual lives with according to 10-year age groups (i.e. number of persons aged 0-9; number of persons aged 10-19; … ; number of persons aged 80+). Subsequently, we use the age-specific infection fatality ratios of Verity and colleagues (2020) to calculate the number persons that are expected to pass away. For ease of interpretation, we multiply this number by 1.000 to represent deaths per 1.000 infections. Age-specific infection fatality ratios were unfortunately not available for men and women separately. In robustness checks, we use age- and sex-specific fatality ratios based on confirmed cases and deaths in Spain (*Actualización nº 104. Enfermedad por el coronavirus (COVID-19)* of the Spanish Ministry of Health; See Appendix A).

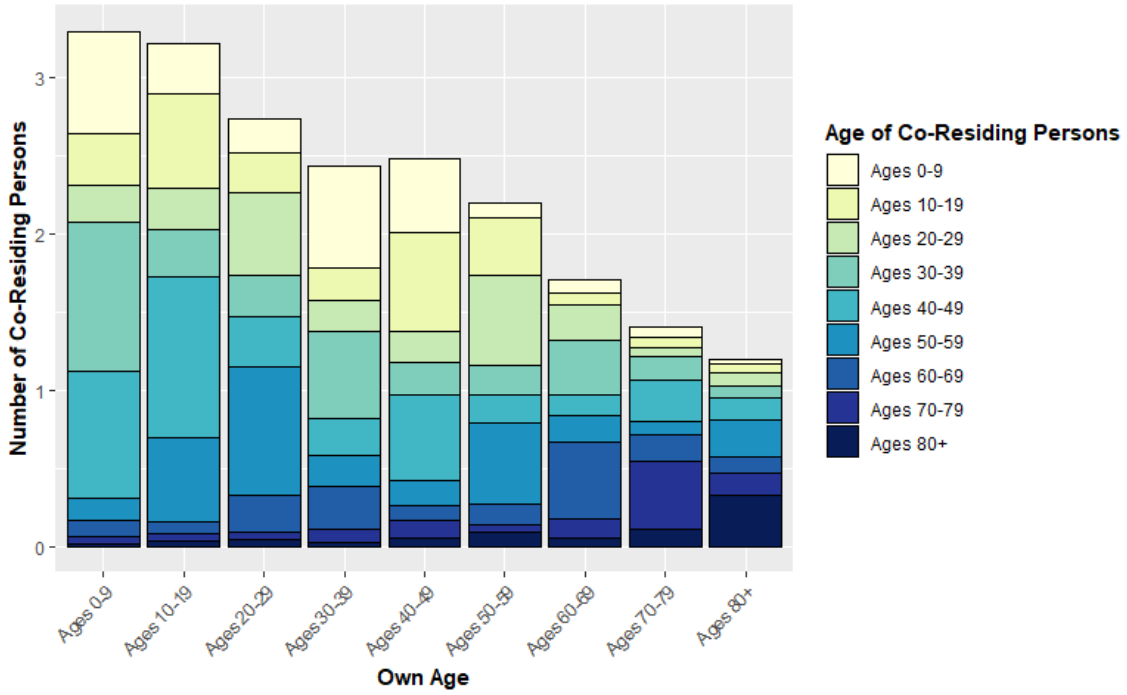
Our indicator of vulnerability is based on the maximum possible number of household transmissions per case and the related expected number of deaths. This number can be adjusted downward proportionally if one assumes that only a share of the household becomes infected, but a complication in that regard is that this indicator does not take into account that the transmission of the virus within households can vary with age (Li et al., 2020).

Results

Figure 1 displays the average number of persons that individuals live with (excluding themselves) according to their own age and the age of co-resident persons. The average number of co-resident persons ranges from 3.3 for young children to 1.2 for the oldest group. Children live with most persons of all age groups.

The age-composition of co-resident persons varies considerably across age groups. Persons aged 0-9 live with 0.02 persons aged 80 or more, on average, whereas persons 80 years or more themselves live with 0.33 other persons aged 80 or more. Other observations that stand out are the high number of persons aged 50-59 that individuals aged 20-29 live with, and the relatively large number of persons aged 80 or more that individuals aged 50-59 live. Both patterns reflect the co-residence of young adults with their parents which is common in the Spanish context due to the late age at which people leave the parental home (Moreno, 2020) and the co-residence of the oldest individuals with their adult children (Esteve et al., 2020b; Reher, 1998).

Figure 1. Average number of co-resident persons by own age and age of co-resident members

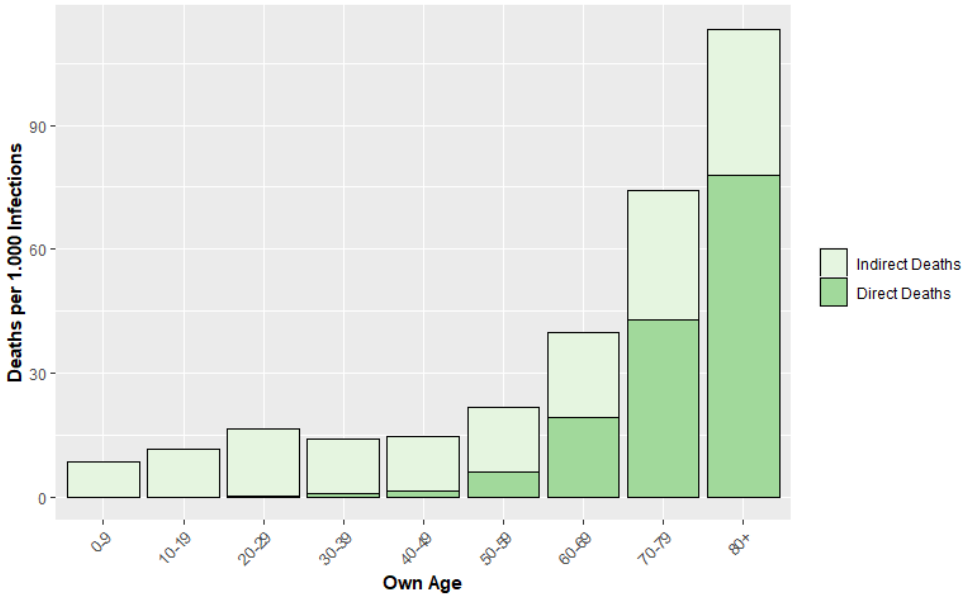


Source: Padrón de habitantes 2018 (INE).

Figure 2 shows, for each age group, the expected number of deaths if 1.000 persons become infected with covid-19 and transmit the virus to all their household members. The dark parts of the bars indicate infected individuals' own risk of passing away, labelled from here onward as "direct deaths". These numbers reflect the infect fatality ratios of Verity and colleagues (2020) used in this paper. The lighter parts of the bars indicate the additional deaths that 1.000 infections are estimated to cause if infected individuals also transmit the virus to *all* other members of their household. We label such cases as "indirect deaths" from here onward.

The estimated number of indirect deaths ranges from an average of 9 deaths per 1.000 infected individuals aged 0 to 9, to 35 deaths per 1.000 infections among persons aged 80 or more. In other words, the number of deaths that could arise from a person above 80 transmitting the virus to other household members is almost 4 times higher than the number of deaths that children aged 0-9 could cause in that manner (the inclusion of persons living in residences would probably increase this difference further). However, the average estimated number of deaths per infection does not vary greatly between age groups below age 60. These numbers range from 9 for children aged 0 to 9 to 16 deaths per 1.000 cases for young adults aged 20-29. The latter group lives with a relatively high number of persons aged 50-69 compared to the other groups below age 60 (See Figure 1). These persons aged 50-69 are most likely their own parents, who have reached ages where covid-19 forms a more serious risk in terms of mortality.

Figure 2. Estimated deaths after 1.000 persons of age group become infected and transmit virus to all household members



Source: Padrón de habitantes 2018 (INE). Deaths calculated assuming all household members become infected.

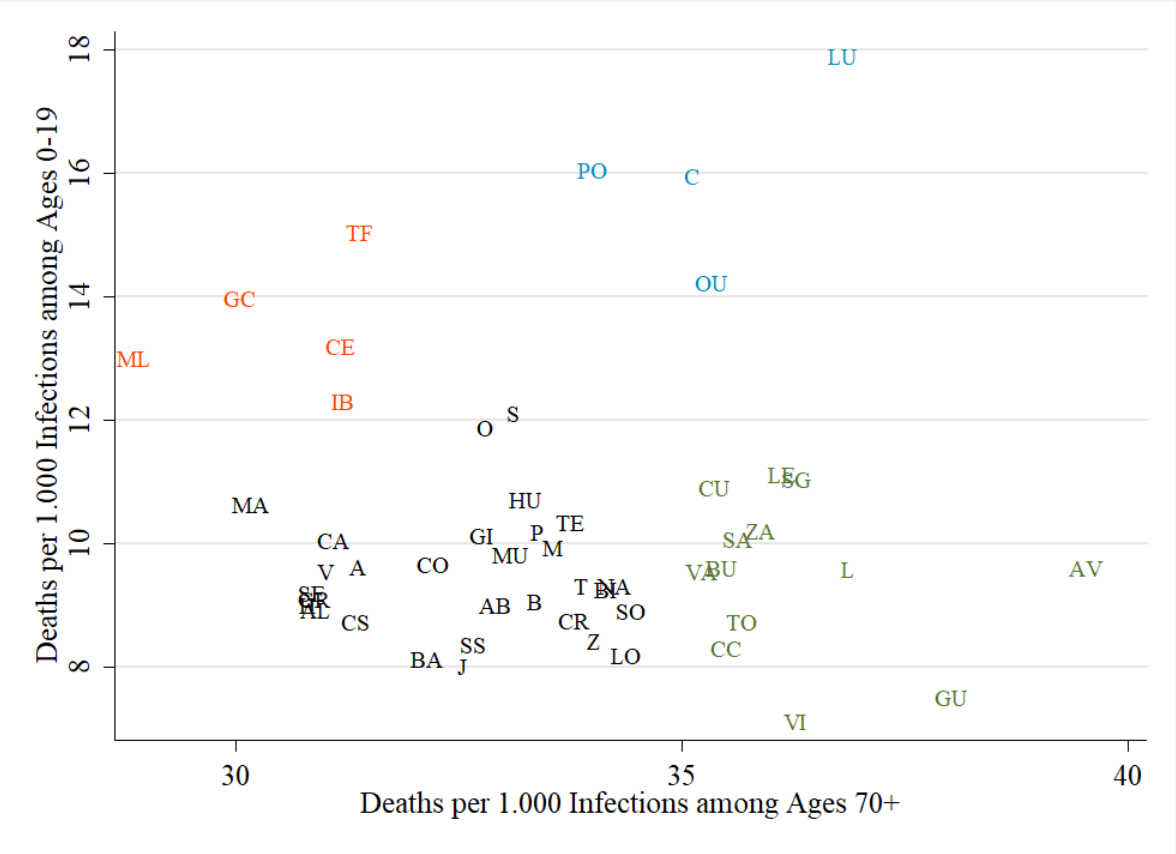
Variation across Provinces

Figure 3 shows how the age-specific estimates of indirect deaths per 1.000 infections (light bars of Figure 2) vary across provinces. Infections among two age groups are contrasted which have been central to many discussions of age-specific policies: persons aged 70+ on the x-axis and persons aged 0-19 on the y-axis. In all provinces, the number of indirect deaths per 1.000 infections is higher for older persons as compared to children. In other words, older persons live with more persons vulnerable to covid-19 (i.e. other older

persons) as compared to younger persons. However, there is a clear variation in age-specific estimates across provinces.

In Ceuta and Melilla, the vulnerability of children's households is relatively high. This implies that children, on average, live with more older persons than in other provinces. At the other extreme, there is a group of provinces with high numbers of indirect deaths after infections among older individuals. In these provinces, many older persons live with their generational peers (probably their partners). This group, situated on the bottom-right corner, consists of provinces from the interior of Spain such as Ávila, Guadalajara, and Lleida. The Galician provinces in the northwestern extreme of Spain (A Coruña, Lugo, Ourense, Pontevedra) combine elements of both previous categories: a high level of vulnerability for the households of both the older and the young. Both intergenerational households and households where older individuals live with peers of their age are relatively common in Galicia. The rest of the provinces have relatively low levels of indirect deaths related to infections of the young and the old (within the Spanish context).

Figure 3. Household's vulnerability to indirect covid-19 related deaths for persons aged 0-19 and persons aged 70+



Orange = Children commonly live with older persons; Green: Older persons commonly live with other older persons; Light-blue: Children and older commonly live with (other) older individuals; Black: Children and older live relatively less often with (other) older individuals.

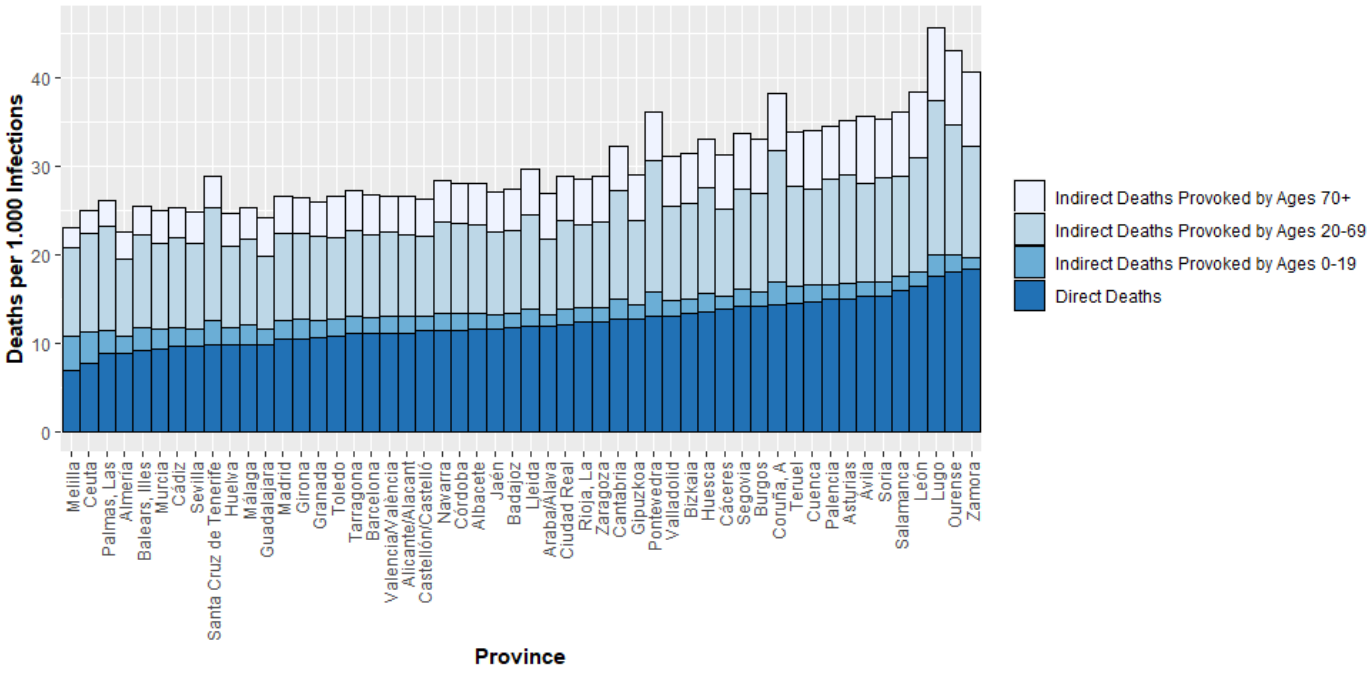
Source: Padrón de habitantes 2018 (INE). Vulnerability calculated assuming all household members become infected and using infect fatality ratios of Verity et al (2020).

Figure 4 shows how age structures and living arrangements shape the overall vulnerability of provinces to covid-19. How many deaths are expected to arise if 1.000 random persons in a given province become infected and infect all other household members? The dark-

blue parts of the bars show the randomly infected persons' own risk of passing away. This estimate varies across provinces due to differences in age structures. In other words, variation in the number of old people makes it more or less likely for a random infection to afflict an older person. Because the northwest of Spain has the oldest populations the number of estimated deaths after 1.000 random persons become infected is twice as high there as compared to several Southern provinces.

The sum of the three lighter parts of the bars of Figure 4 indicates the number of deaths that can be induced by the within-household transmission of covid-19. Because the age-structure of the province also matters here, the total size of the lighter bars roughly follows the order of the dark-blue bars of Figure 4. Deviations from this general pattern are caused by variation across provinces in who older individuals live with. In other words, in provinces where older persons live in large households, this estimate will be higher than expected and vice versa. The provinces that stand out in this regard are, as expected, the Galician provinces, and, to a lesser extent, provinces with high levels of co-residence of older persons with generational peers (León, Lleida, Zamora) and provinces with high levels of intergenerational residence such as the provinces in Africa.

Figure 4. Estimated deaths after 1.000 persons in province become infected and transmit virus to all household members



Source: Padrón de habitantes 2018 (INE). Deaths calculated assuming all household members become infected and using infect fatality ratios of Verity et al (2020).

The lighter parts of the bars are broken down by the contribution of infections among three broad age groups to the estimated number of indirect deaths (i.e. indirect deaths are broken down by the age of the person who got randomly infected and transmitted the virus to household members). In general, the contribution of children is larger in provinces with younger populations (on the left of the panel), whereas the contribution of ages 70+ matters more in provinces with aged populations (on the right of the panel). This suggests that in aged populations there are relatively more households where older persons live with

generational peers. In younger populations (and Galicia), the transmission within intergenerational households is relatively more important than in older populations.

Section 4: Discussion

The propagation and consequences of the covid-19 pandemic depend, among many other factors, on the extent to which the virus can be transmitted within households. In this paper, we documented variation in co-residence patterns and related vulnerability to mortality due to covid-19 infections across age groups and Spain's provinces. We obtained three main findings that can help inform policies related to covid-19.

Firstly, children live in the largest households of all age groups and can play an important role in propagating the virus (depending on the extent to which actual transmission probabilities vary by age; Li et al., 2020; Danis et al., 2020). At the same time, the relatively low number of older persons that children co-reside with reduces the risk of deaths that can arise due to children transmitting the virus to household members. Among individuals below age 60, infections of persons aged 20-29 have the highest risk of causing deaths due to within household-transmission. Many young adults live with their parents who have entered ages that make them more vulnerable to covid-19. At the same time, the vulnerability of households varies relatively little across age groups until age 60. The households of the oldest are the most vulnerable, not only because of their own risk of dying but also because they are the most likely to live with other older persons. Nonetheless, in our simulation, most indirect deaths would be provoked by individuals

below age 70 because of differences in the absolute size of age groups. A limitation of our analysis is that we did not take into account other factors that can affect the vulnerability of households, most importantly morbidity. If older persons with medical conditions are less likely to live with other older persons, this might lead to a less steep age gradient in vulnerability. At the same, time our results only referred to individuals living in private households. The inclusion of old-age homes would accentuate the results by age.

Secondly, the co-residence patterns of older persons differ considerably between provinces. We distinguished between older persons living with peers of their age, and older persons living in inter-generational households. Inter-generational households lead to relatively high vulnerability of children's households in several provinces (Canary Islands, Ceuta, Melilla and Galicia). In these provinces, policies affecting the confinement of younger age groups are likely to have a relatively larger impact on the transmission of the virus within households to the older population. In contrast, several provinces in the interior of Spain stand out in terms of the vulnerability of older people's households. In these provinces, many older persons live with peers of their age, most likely their partners. Given that these provinces also have the oldest populations, this poses a double challenge for aged populations. Not only do aged populations have more persons at risk of dying from covid-19, the at-risk population is also to an important extent concentrated in the same households. This might especially be the case in Galicia, where both the challenges related to inter-generational households *and* the co-residence of older individuals with their peers exist. Fortunately, so far, Galicia is one of the regions of Spain with relatively few actual cases of covid-19. This underlines the nature and limitations of our analysis, which aims at

estimating the risk of people dying *if* a person becomes infected and *if* all household members become infected too.

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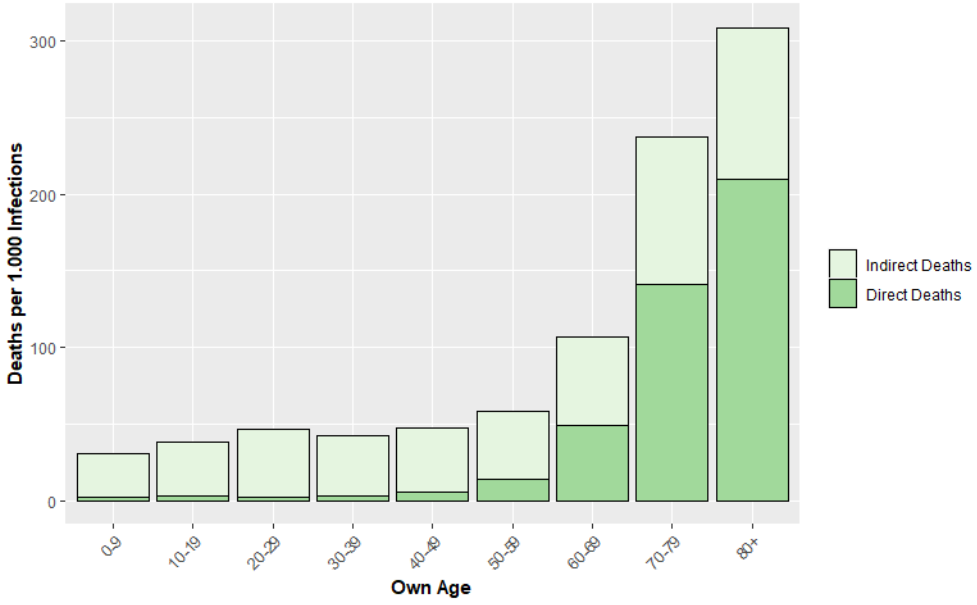
Appendix A. Replication using fatality ratios of confirmed cases in Spain

In robustness checks we used the case fatality ratios as calculated and reported by the Spanish Ministry of Health on the 13th of May 2020. These numbers are available at https://www.mscbs.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov-China/documentos/Actualizacion_104_COVID-19.pdf

More specifically, the age-specific fatality ratios employed are: Ages 0-9: 0.2%; Ages 10-19: 0.3%; Ages 20-29: 0.2%; Ages 30-39: 0.3%; Ages 40-49: 0.6%; Ages 50-59: 1.4%; Ages 60-69: 4.9%; Ages 70-79: 14.1%; Ages 80-89: 20.8%; Ages 90+=22.0%.

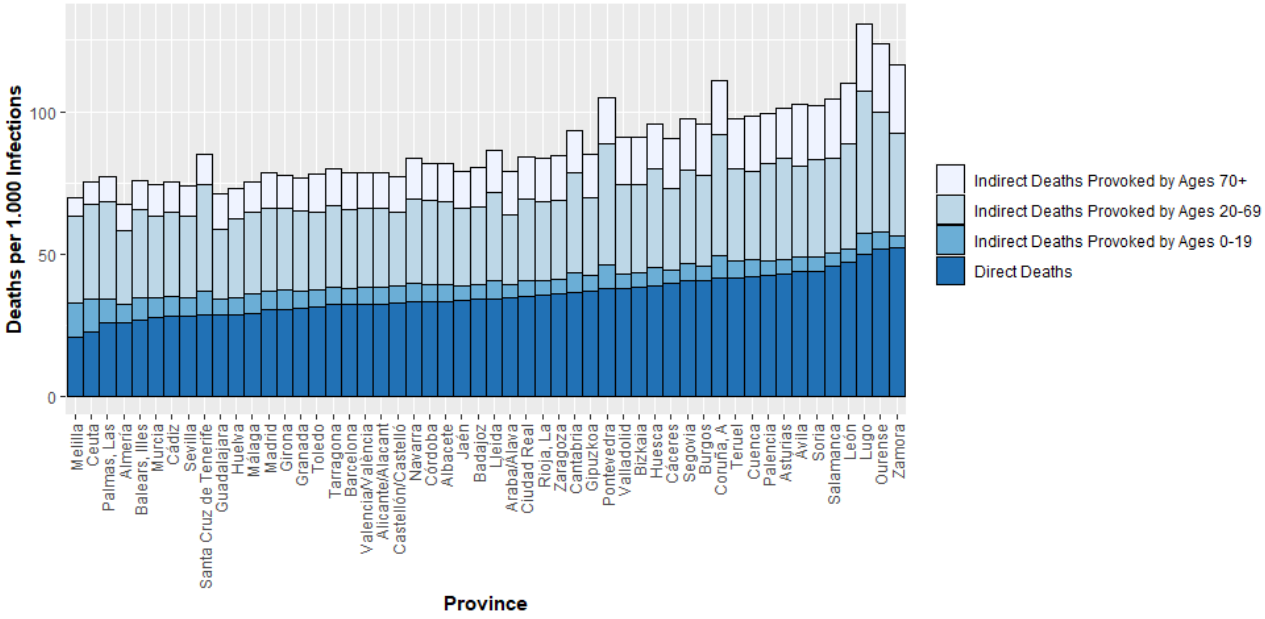
These fatality ratios are much higher because they do not take into account non-confirmed cases. The fatality ratios for children are higher in particular (in relative terms). This becomes visible once replicating Figure 2 using these fatality ratios (Figure A2). At the same time, the ordering of age groups and provinces changes little once using these alternative fatality ratios (See Figure A4).

Figure A2. Estimated deaths after 1.000 persons of age group become infected and transmit virus to all household members



Source: Padrón de habitantes 2018 (INE). Deaths calculated assuming all household members become infected and using infect fatality ratios of confirmed cases in Spain as reported by Spanish Ministry of Health on 15/05/2020.

Figure A4. Estimated deaths after 1.000 persons in province become infected and transmit virus to all household members



Source: Padrón de habitantes 2018 (INE). Deaths calculated assuming all household members become infected and using infect fatality ratios of confirmed cases in Spain as reported by Spanish Ministry of Health on 15/05/2020.

B. Analysis for men and women separately

Using confirmed case fatality ratios has the advantage of enabling an analysis for men and women separately. The confirmed case fatality ratios for men are:

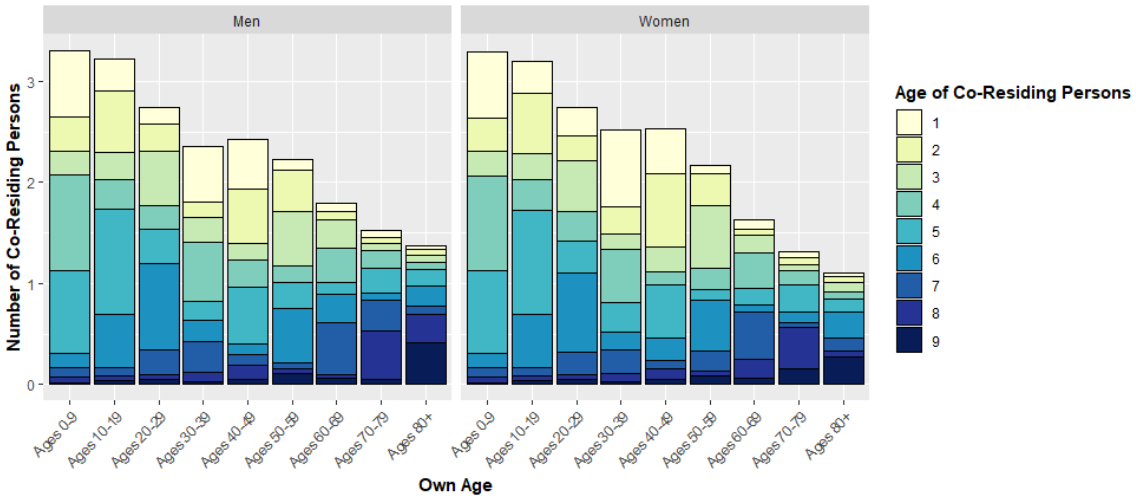
Ages 0-9: 0.2%; Ages 10-19: 0.3%; Ages 20-29: 0.3%; Ages 30-39: 0.5%; Ages 40-49: 0.9%; Ages 50-59: 2.4%; Ages 60-69: 6.7%; Ages 70-79: 17.4%; Ages 80-89: 27.7%; Ages 90+=30.7%.

And for women:

Ages 0-9: 0.3%; Ages 10-19: 0.3%; Ages 20-29: 0.1%; Ages 30-39: 0.2%; Ages 40-49: 0.3%; Ages 50-59: 0.7%; Ages 60-69: 3.0%; Ages 70-79: 10.0%; Ages 80-89: 15.8%; Ages 90+=18.6%.

Figures B1 and B2 show results for men and women separately. General patterns for men and women are similar, the number of co-resident persons declines with age, but the age of these co-resident persons increases.

Figure B1. Average number of co-resident persons by own age and age of co-resident members



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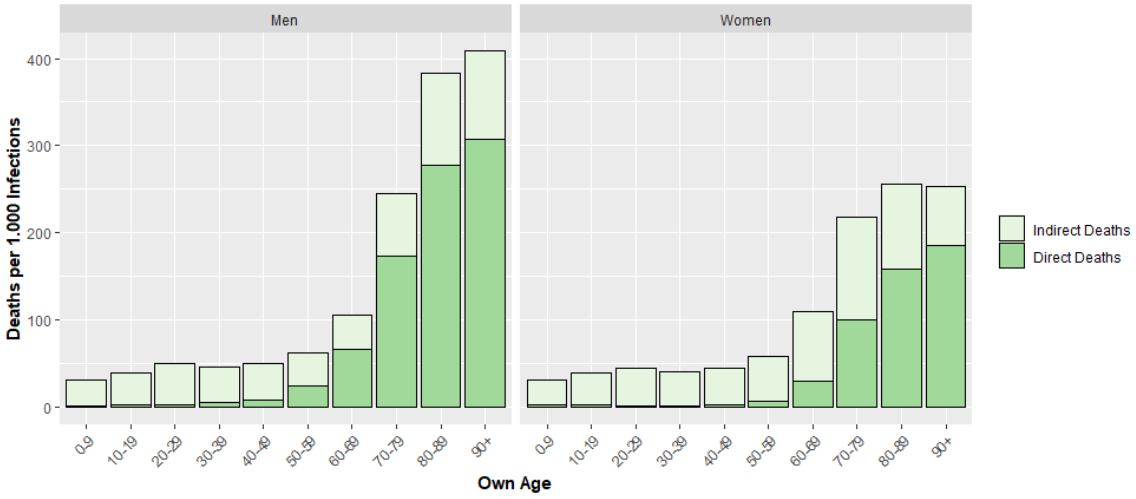

At the same time, the number of indirect deaths per 1.000 infections start to vary between men and women after age 50. Women aged 50-79 have higher risks of causing a death

through household transmission as they are more likely to live with an older person. This probably reflects age differences within romantic relationships, where men are on average older than women. This pattern turns around after ages 80, where men are more likely to cause indirect deaths than women. Because women live longer they are less likely to live with a partner at advanced ages than men.