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Supplementary information

Age-specific mortality and immunity patterns of SARS-CoV-2

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Supplementary Information

Age-specific mortality and immunity patterns of SARS-CoV-2

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Country/Region	Study Period	N	Assay Sensitivity/ Specificity	Unadjusted Prevalence (%)	Adjusted Prevalence (%)	Population	Age	Source
Belgium	03/03/2020 – 05/04/2020	3,910	87.8/99.2%	2.9%	2.4% [a]	General	0-101	[36]
	20/04/2020 – 26/04/2020	3,397	87.8/99.2%	6.0%	6.0% [a]	General	0-101	[36]
	18/05/2020 – 25/05/2020	3,242	87.8/99.2%	6.9%	7.0% [a]	General	0-101	[36]
	08/06/2020 – 13/06/2020	2,960	87.8/99.2%	5.5%	5.4% [a]	General	0-101	[36]
	29/06/2020 – 03/07/2020	3,023	87.8/99.2%	4.5%	4.3% [a]	General	0-101	[36]
	14/04/2020 – 16/04/2020	900	-	4.8%	-	Blood donors	18-75	[37]
	27/04/2020 – 29/04/2020	900	-	4.7%	-	Blood donors	18-75	[37]
	11/05/2020 – 13/05/2020	900	-	4.7%	-	Blood donors	18-75	[37]
	25/05/2020 – 27/05/2020	900	-	5.1%	-	Blood donors	18-75	[37]
	08/06/2020 – 10/06/2020	900	-	4.3%	-	Blood donors	18-75	[37]
Czech Republic	23/04/2020 – 01/05/2020	26,549	95.0/100%	0.4%	0.4%	General	18-89	[38]
Denmark	06/04/2020 – 08/04/2020	4,072	82.6/99.5%	1.7% [b]	1.5%	Blood donors	17-69	[39,40]
	14/04/2020 – 19/04/2020	5,326	82.6/99.5%	2.1% [b]	1.9%	Blood donors	17-69	[39,40]
	20/04/2020 – 26/04/2020	5,820	82.6/99.5%	1.8% [b]	1.6%	Blood donors	17-69	[39,40]
	27/04/2020 – 03/05/2020	5,422	82.6/99.5%	2.5% [b]	2.4%	Blood donors	17-69	[39,40]
England	26/04/2020 – 13/06/2020	1,757	99.1/99.0%	6.3% [b]	5.4%	General	16+	[41]
	20/06/2020 – 13/07/2020	109,07	84.4/98.6%	5.1%	6.0% [a]	General	18+	[42]
Finland	13/04/2020 – 19/04/2020	362	100/100%	0.3%	0.3%	General	18-69	[43]
	20/04/2020 – 26/04/2020	674	100/100%	0.3%	0.3%	General	18-69	[43]
	27/04/2020 – 03/05/2020	426	100/100%	0.5%	0.5%	General	18-69	[43]
	04/05/2020 – 10/05/2020	514	100/100%	0.0%	0.0%	General	18-69	[43]
	11/05/2020 – 17/05/2020	401	100/100%	0.3%	0.3%	General	18-69	[43]
	18/05/2020 – 24/05/2020	210	100/100%	0.5%	0.5%	General	18-69	[43]
	25/05/2020 – 31/05/2020	178	100/100%	0.0%	0.0%	General	18-69	[43]
	01/06/2020 – 07/06/2020	214	100/100%	0.5%	0.5%	General	18-69	[43]
France	11/05/2020 – 17/05/2020	3,529	90.5/100%	4.5% [b]	4.9%	General	0+	[44]
Geneva	06/04/2020 – 10/04/2020	341	93.0/100%	3.5%	4.8% [a]	General	5+	[8]

	14/04/2020 – 17/04/2020	469	93.0/100%	6.0%	8.5%[a]	General	5+	[8]
	20/04/2020 – 24/04/2020	577	93.0/100%	10.6%	10.9%[a]	General	5+	[8]
	27/04/2020 – 02/05/2020	604	93.0/100%	6.0%	6.6%[a]	General	5+	[8]
	04/05/2020 – 09/05/2020	775	93.0/100%	10.6%	10.8%[a]	General	5+	[8]
Hungary	01/05/2020 – 16/05/2020	10,406	92.7/99.9%	0.7%	0.6%	General	14+	[45]
Italy	25/05/2020 – 15/07/2020	64,660	92.7/99.9%	2.5%	2.6%	General	0+	[46]
Kenya	30/04/2020 – 16/06/2020	3,098	83.0/99.0%	5.6%	5.2%[a]	Blood donors	15-64	[47]
Luxembourg	15/04/2020 – 05/05/2020	1,862	85.7/99.5%	1.6%	1.3%[a]	General	18-79	[48]
Netherlands	01/04/2020 – 15/04/2020	7,361	86.0/99.6%	3.1%	2.7%	Blood donors	18-72	[49]
	01/04/2020 – 17/04/2020	2,096	85.0/99.0%	3.6%	3.1%	General	2+	[50]
	11/05/2020 – 18/05/2020	7,150	98.7/99.6%	5.9%	5.6%	Blood donors	18-72	[51]
New York City	19/04/2020 – 28/04/2020	5,946	87.9/99.8%	22.2%	22.7%[a]	General	18+	[9]
New York State	19/04/2020 – 28/04/2020	15,101	87.9/99.8%	12.5%	14.0%[a]	General	18+	[9]
Portugal	21/05/2020 – 08/07/2020	2,301	93.0/99.6%	2.9%	2.7%	General	1+	[52]
Rio de Janeiro	14/04/2020 – 18/04/2020	1,565	85.0/99.0%	1.7%	2.8%[a]	Blood donors	18-69	[53]
	19/04/2020 – 23/04/2020	623	85.0/99.0%	3.2%	4.5%[a]	Blood donors	18-69	[53]
	24/04/2020 – 27/04/2020	669	85.0/99.0%	4.3%	5.3%[a]	Blood donors	18-69	[53]
Scotland	17/03/2020 – 17/03/2020	500	94.1/100%	0.0%	0.0%	Blood donors	18-75	[54]
	21/03/2020 – 23/03/2020	500	94.1/100%	1.2%	1.3%	Blood donors	18-75	[54]
	20/04/2020 – 26/04/2020	443	-	-	6.8%	General	0+	[55]
	27/04/2020 – 03/05/2020	543	-	-	4.3%	General	0+	[55]
	04/05/2020 – 10/05/2020	530	-	-	3.1%	General	0+	[55]
	11/05/2020 – 17/05/2020	521	-	-	2.6%	General	0+	[55]
	18/05/2020 – 24/05/2020	547	-	-	1.9%	General	0+	[55]
	25/05/2020 – 30/05/2020	527	-	-	2.9%	General	0+	[55]
	01/06/2020 – 07/06/2020	544	-	-	3.7%	General	0+	[55]
	08/06/2020 – 14/06/2020	553	-	-	5.2%	General	0+	[55]
	15/06/2020 – 21/06/2020	536	-	-	4.4%	General	0+	[55]
Slovenia	10/04/2020 – 10/04/2020	1,318	92.0/99.0%	3.1%	2.3%	General	0-99	[56]
Spain	27/04/2020 – 11/05/2020	51,958	100/99.9%	4.6%	4.5%	General	0+	[7]
Sweden[c]	20/04/2020 – 26/04/2020	1,200	98.9/99.4%	5.7%[b]	5.2%	Hospital	0-95	[57]
	27/04/2020 – 03/05/2020	1,200	98.9/99.4%	4.6%[b]	4.1%	Hospital	0-95	[57]

	04/05/2020 – 10/05/2020	1,200	98.9/99.4%	4.6% [b]	4.1%	Hospital	0-95	[57]
	11/05/2020 – 17/05/2020	1,200	98.9/99.4%	5.1% [b]	4.6%	Hospital	0-95	[57]
	18/05/2020 – 24/05/2020	1,200	98.9/99.4%	5.9% [b]	5.4%	Hospital	0-95	[57]
	25/05/2020 – 31/05/2020	1,200	98.9/99.4%	6.1% [b]	5.6%	Hospital	0-95	[57]
	01/06/2020 – 07/06/2020	1,200	98.9/99.4%	7.5% [b]	7.0%	Hospital	0-95	[57]
	08/06/2020 – 14/06/2020	1,200	98.9/99.4%	6.1% [b]	5.6%	Hospital	0-95	[57]
	20/04/2020 – 26/04/2020	400	98.9/99.4%	1.2% [b]	0.6%	Blood donors	18-75	[57]
	27/04/2020 – 03/05/2020	400	98.9/99.4%	3.2% [b]	2.6%	Blood donors	18-75	[57]
	04/05/2020 – 10/05/2020	400	98.9/99.4%	3.5% [b]	2.9%	Blood donors	18-75	[57]
	11/05/2020 – 17/05/2020	400	98.9/99.4%	5.7% [b]	5.2%	Blood donors	18-75	[57]
	18/05/2020 – 24/05/2020	400	98.9/99.4%	5.6% [b]	5.1%	Blood donors	18-75	[57]
	25/05/2020 – 31/05/2020	400	98.9/99.4%	4.6% [b]	4.1%	Blood donors	18-75	[57]
	01/06/2020 – 07/06/2020	400	98.9/99.4%	5.7% [b]	5.2%	Blood donors	18-75	[57]
	08/06/2020 – 14/06/2020	400	98.9/99.4%	7.8% [b]	7.1%	Blood donors	18-75	[57]

Table S1. Seroprevalence studies.

[a] Estimates are additionally adjusted for population demographics. [b] Unadjusted seroprevalence values were calculated using the reported values of assay sensitivity and specificity. [c] The number of samples is reported as approximately 1,200 samples per week and 400 per week in the case of blood donor samples[57]. As the exact sample sizes per week are not reported we assume these to be the exact number of samples.

Supplementary Methods

S1. Relative risk of COVID-19 death by age

To explore the risk of reported COVID-19 death by age in each country age-specific relative risks (RR) of death were calculated as shown in equation 1, where $D_{c,a}$ and $N_{c,a}$ are the country and age-specific number of deaths and population size, respectively. The age-group 55-59 was chosen as the preferential reference group as it is less likely to be influenced by deaths associated with outbreaks in nursing home settings. As the reported age-groups varied by country, the age group with an upper bound of 59 was chosen as the reference group where possible. Where this was not an available age-group, the age-group with an upper bound of 64 was selected as the reference.

$$RR_{c,a} = \frac{D_{c,a} / N_{c,a}}{D_{c,55-59} / N_{c,55-59}}$$

[Equation 1]

S2. Inferring IFR estimates amongst ≥65s

We fit our model exclusively to deaths <65 years. We use age-specific death data for England, reported by the Office of National Statistics (ONS)[30], to derive IFR estimates for age groups ≥65, explicitly excluding age-specific nursing home deaths and assuming a baseline relative infection attack rate of 0.7 for those aged 65+ relative to individuals aged <65 as shown in Equation 2.

$$IFR_{a,s} = \frac{D_{a,s}}{N_{a,s} \cdot \Lambda \cdot \delta_a}$$

[Equation 2]

Here, $D_{a,s}$ is the number of age and sex-specific non-nursing home COVID-19 deaths, $N_{a,s}$is the age and sex-specific population size, Λ is the cumulative probability of infection and $\delta_a$is the age-specific relative infection attack rate. For 13 additional countries where the proportion of COVID-19 deaths attributable to nursing homes had been reported, the age- and sex- specific number of non-nursing home COVID-19 deaths were calculated by assuming that all COVID-19 deaths that occurred in nursing homes were aged 65+ and that the age-sex-distribution of these deaths follows the same age-sex-distribution as all COVID-19 deaths ≥65 years. This adjustment was applied to each of the 13 countries assuming the cumulative proportions to be constant in time (Table S2). In the case of France, deaths that occurred in nursing homes are reported separately to those that occurred in hospital. As minimal proportions of reported hospitalised deaths are expected to be attributable to nursing home residents, we treat the reported hospitalised deaths in France as non-nursing home deaths. To assess the generalizability of IFRs ≥65 derived from this data, we apply them to the 13 additional countries and find that they can reconstruct the number of non-nursing home deaths relatively well in these countries (Figure 1C).

Country	Date of Reporting	% (LTC/Total COVID-19 deaths)
Denmark[3]	15/06/2020	35.28% (211/598)
England[41]	30/06/2020	30.19% (13,417/44,440)
Finland[58]	23/06/2020	44.95% (147/327)
France[59]	20/09/2020	33.97% (10,560/31,088)
Germany[3]	23/06/2020	39.25% (3,491/8,895)
Hungary[3]	02/06/2020	23.87% (127/532)
Ireland[3]	22/06/2020	63.25% (1,086/1,717)
Northern Ireland[60]	11/09/2020	39.68% (352/887)
Norway[61]	14/09/2020	57.49% (142/247)
Portugal[3]	09/05/2020	40.00% (450/1125)
Scotland[62]	07/09/2020	46.41% (1,966/4,236)
Sweden[3]	15/06/2020	47.40% (2,280/4,810)
Switzerland[63]	12/05/2020	53.00% (927/1,749)
Wales[26]	30/06/2020	28.99% (645/2,225)

Table S2. The proportion of reported COVID-19 deaths attributable to nursing home/long-term care (LTC) settings for 13 countries.

S3. Population IFR estimates and nursing home transmission

To account for nursing home deaths in the estimation of IFR, we define 2 distinct populations - that of nursing home residents, N_{NH}, and that of the general population excluding nursing home residents, N_g. For each of these populations we derive single population-weighted IFR values, IFR_g and IFR_{NH} (Figure 4B), using the age and sex-specific IFR estimates produced by the ensemble model and the demographic distributions of each population as shown in equations 3 and 4. $IFR_{a,s}$ is the age and sex-specific IFR estimates from the ensemble model, $\alpha_{a,s}$ is the proportion of the population in age group a and sex s, and γ is the frailty of nursing home residents relative to that of the general population of the same age and sex.

$$IFR_g = \sum IFR_{a,s} \cdot \alpha_{a,s}$$

[Equation 3]

$$IFR_{NH} = \gamma \cdot \sum IFR_{a,s} \cdot \alpha_{a,s}$$

[Equation 4]

To demonstrate how varying levels of transmission in nursing home settings can affect estimates of IFR (Figure 4C) we apply a simplified calculation of the overall IFR, shown in equation 5. Here, the total number of COVID-19 deaths in nursing home settings, D_{NH}, is varied through values of the nursing home infection attack rate, λ_{NH}, and relative frailty, γ, as shown in equation 6, where values of γ>1 represents increased frailty of nursing home residents relative to that of the general population. The total number of COVID-19 deaths in the general population, D_g, the infection attack rate of the general population, λ_g, and the population sizes of both the general and nursing home populations, N_g and N_{NH} remain fixed.

$$IFR = \frac{D_g + D_{NH}}{\lambda_g \cdot N_g + \lambda_{NH} \cdot N_{NH}}$$

[Equation 5]

$$D_{NH} = \gamma \cdot IFR_{NH} \cdot \lambda_{NH}$$

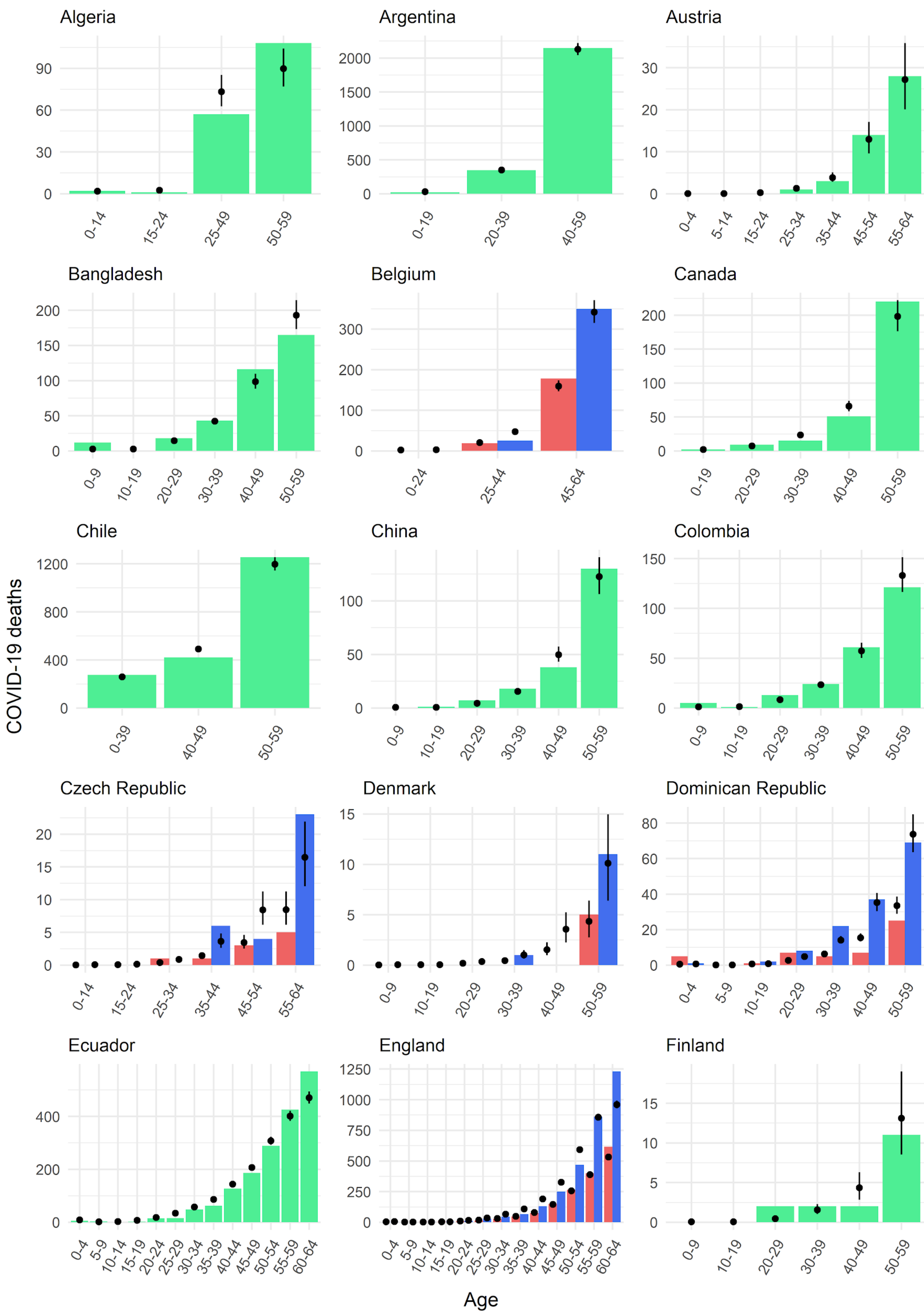
[Equation 6]

Using the total number of reported COVID-19 deaths attributed to nursing home residents the infection attack rate in nursing home settings can be approximated, shown in Equation 7, under different scenarios of the relative frailty of nursing home residents, γ.

$$\lambda_{NH} = \frac{D_{NH}}{\gamma \cdot IFR_{NH} \cdot N_{NH}}$$

[Equation 7]

Supplementary Figures & Tables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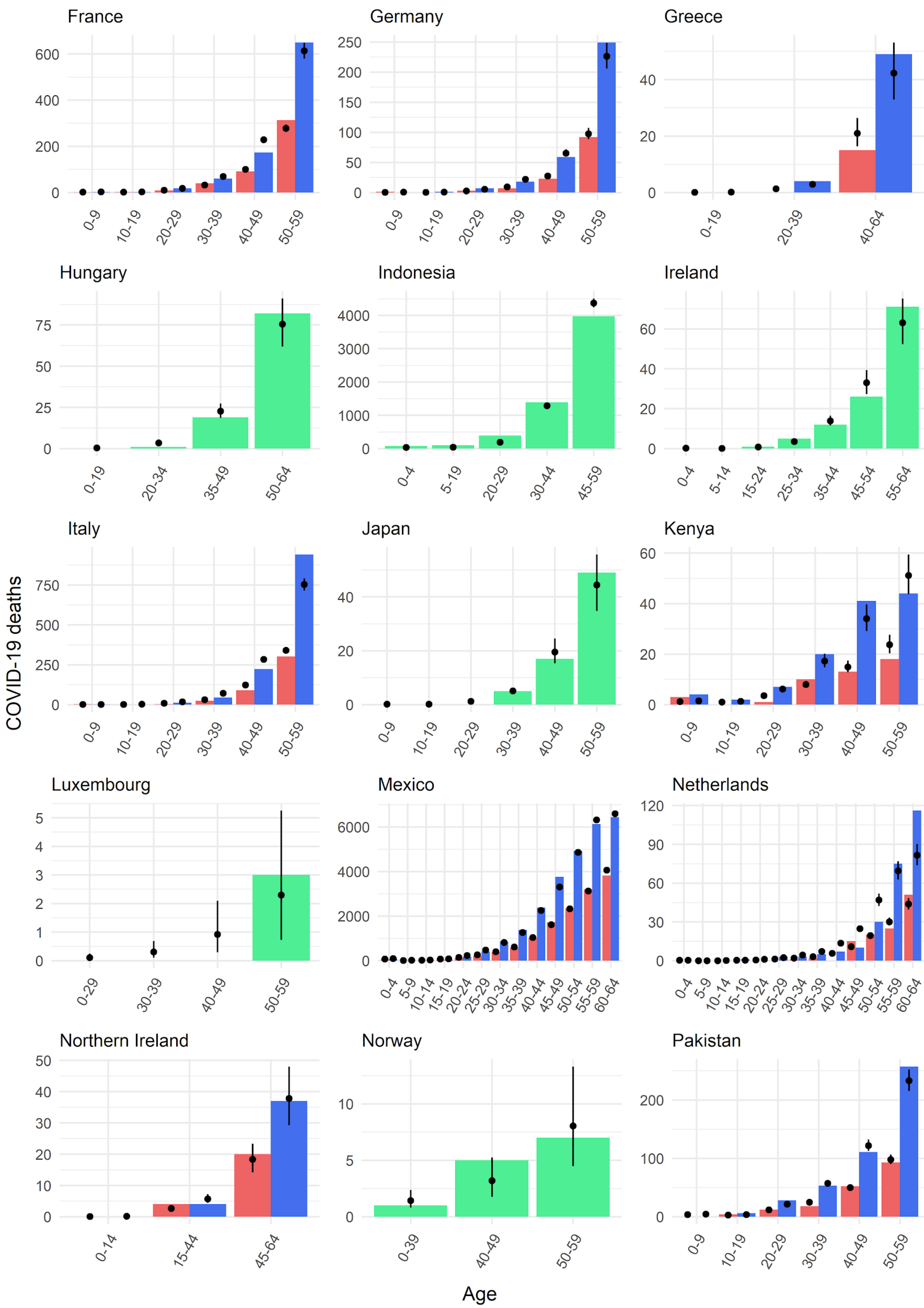
COVID-19 deaths
Age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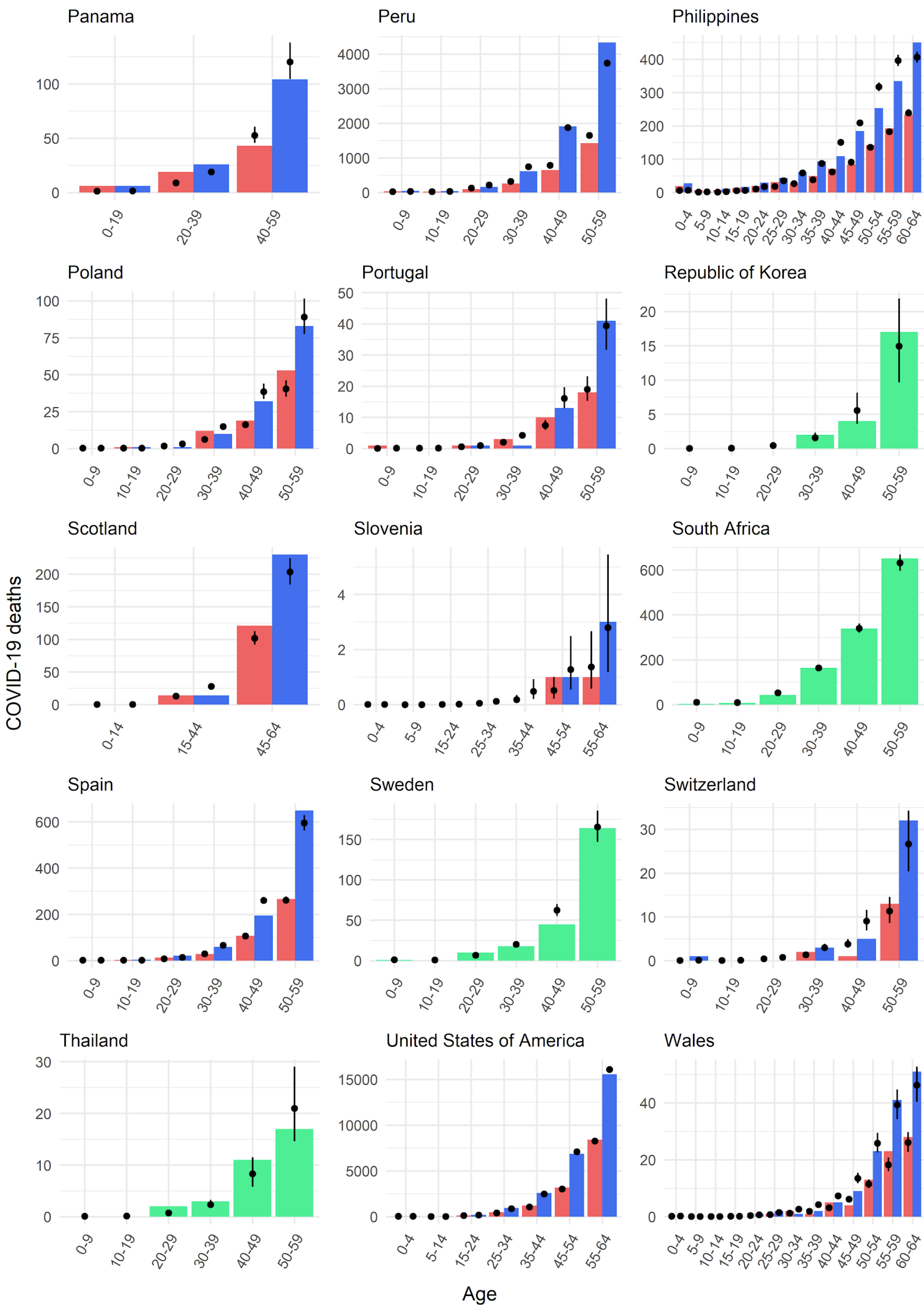
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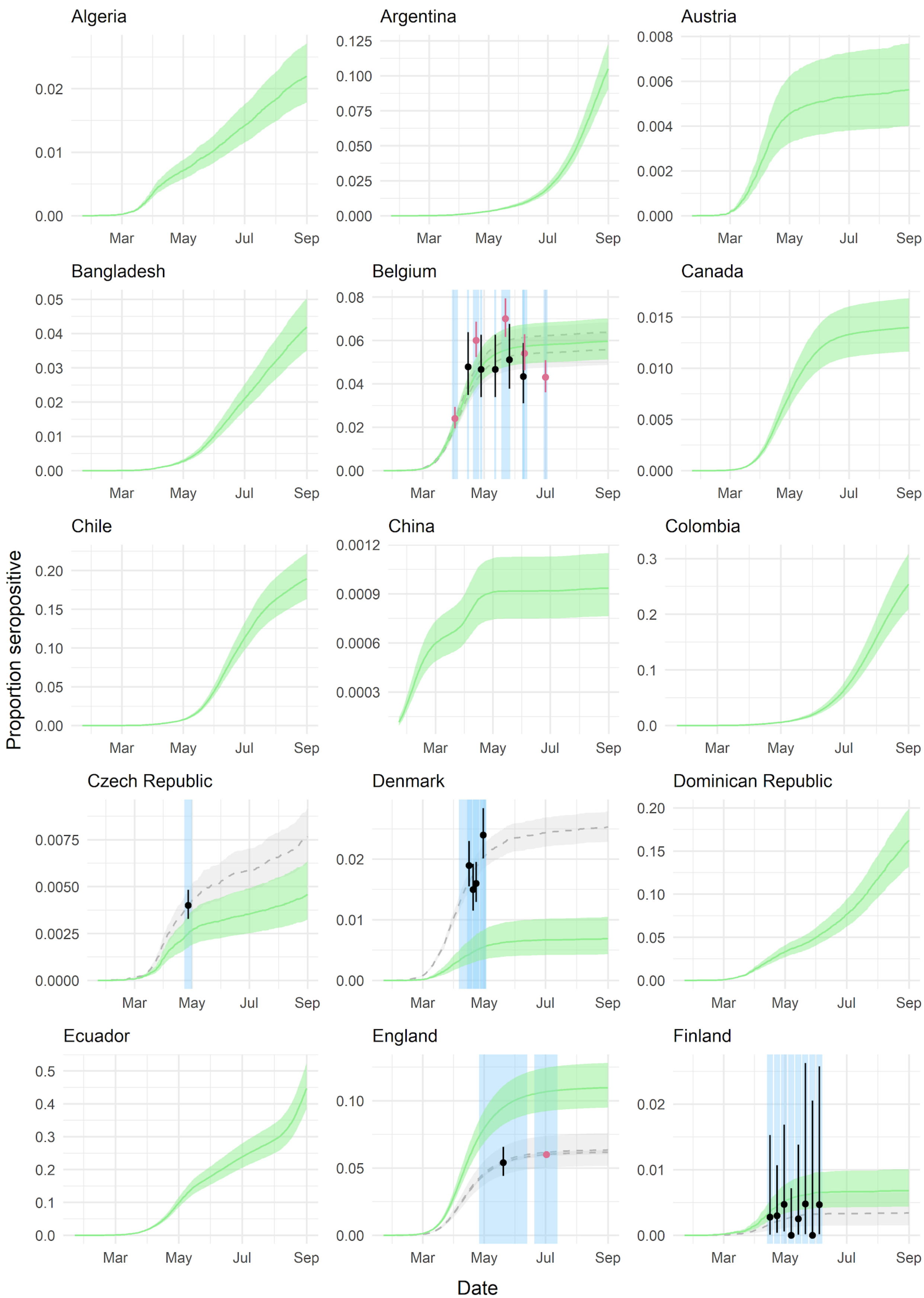
United States of America
Wales
COVID-19 deaths
Age

Figure S1. Fit to age-specific death data in age groups <65. Coloured bars represent the observed age-specific number of deaths in each country (blue=male, red=female, green=both). Black points and lines represent the median and 95% credible interval model estimates.



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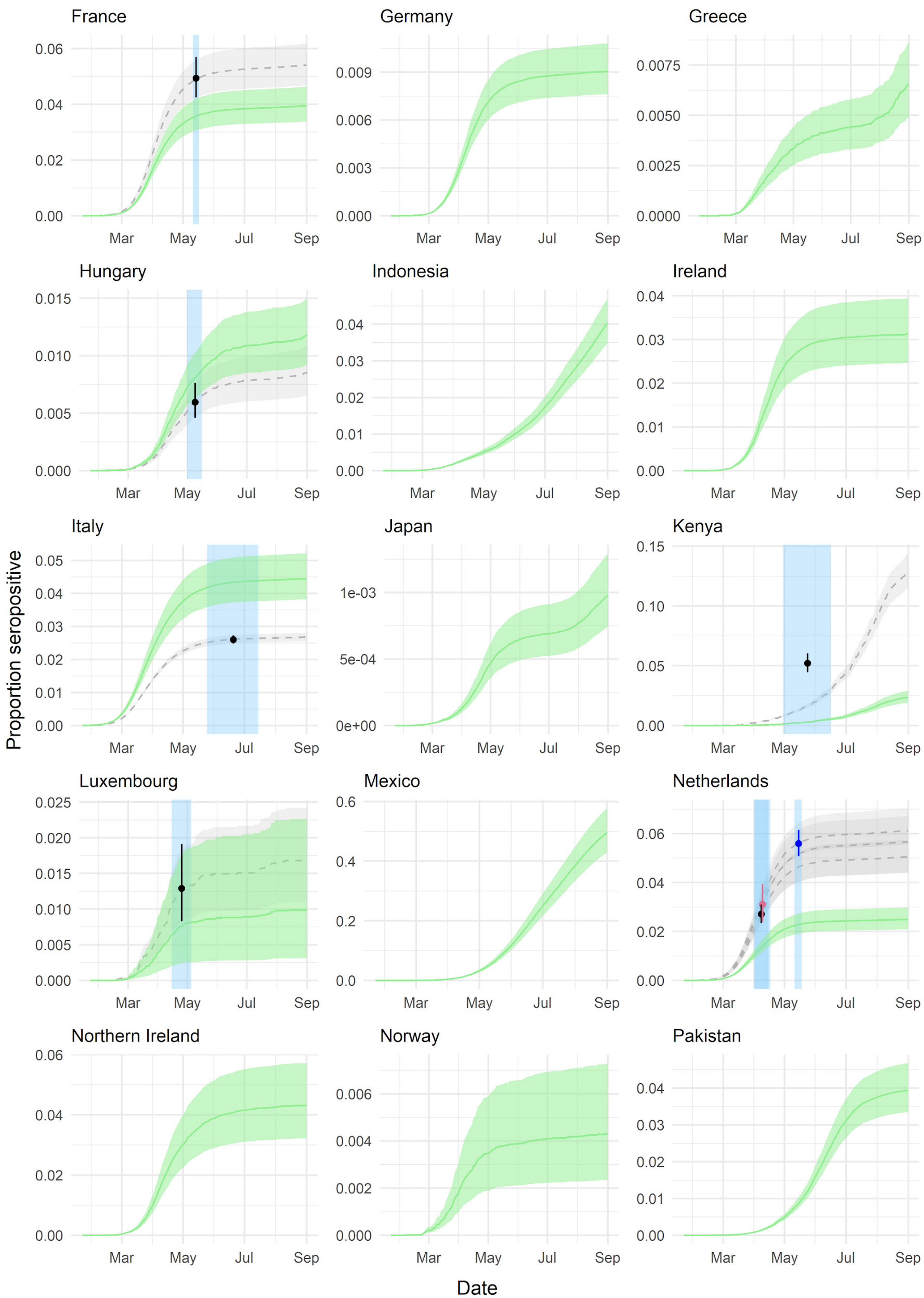
Proportion seropositive
Date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Proportion seropositive
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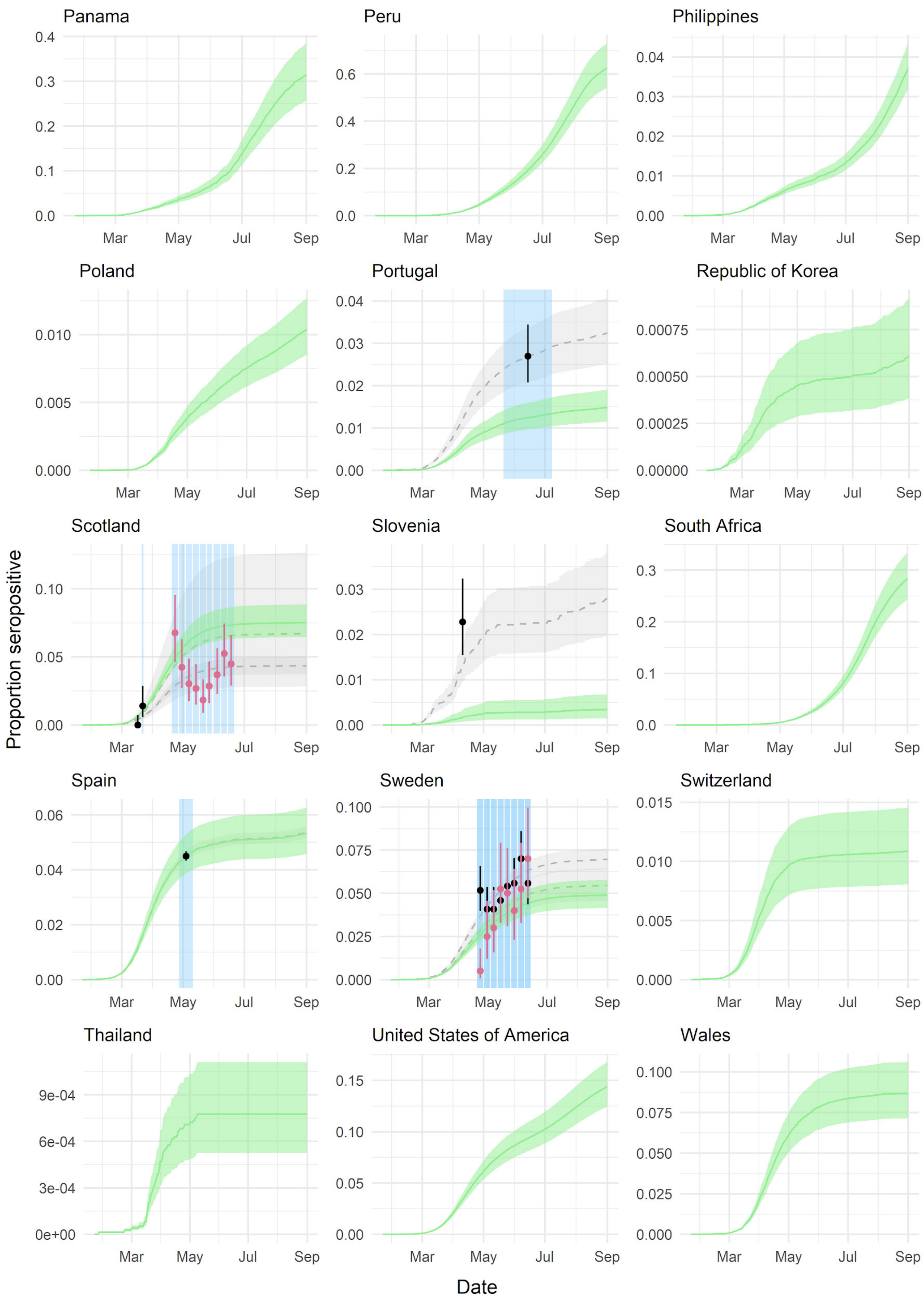
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Thailand
United States of America
Wales
Proportion seropositive
Date
Mar
May
Jul
Sep

Figure S2. Estimates of the proportion seropositive over time. The green line and ribbons represent the median and 95% credible interval estimates of the proportion seropositive over time. Coloured points and lines represent the proportion seropositive as reported by seroprevalence studies and the blue shading shows the timing of each seroprevalence sampling period.

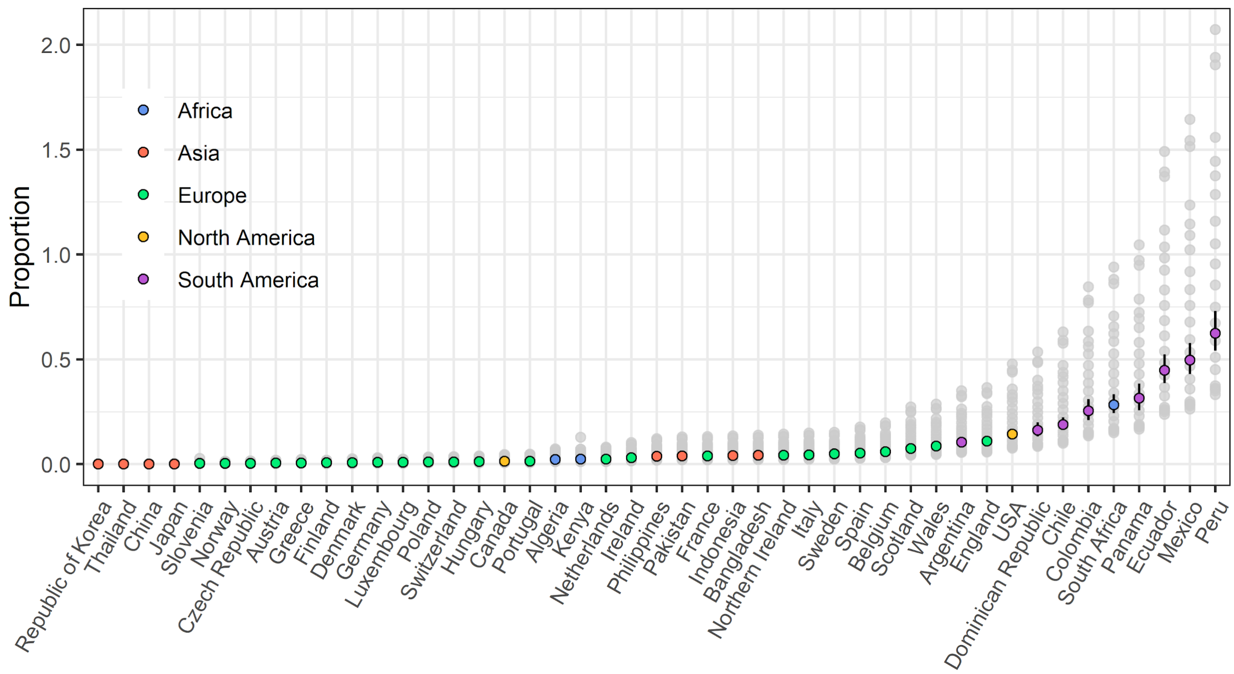


Figure S3. Estimates of the infected population proportion for each country as of the 1st of September 2020. Grey shaded dots indicate the median estimates by fitting the model with each individual seroprevalence survey. Coloured dots and lines represent the median and 95% credible intervals (CrI) estimated by the ensemble model.

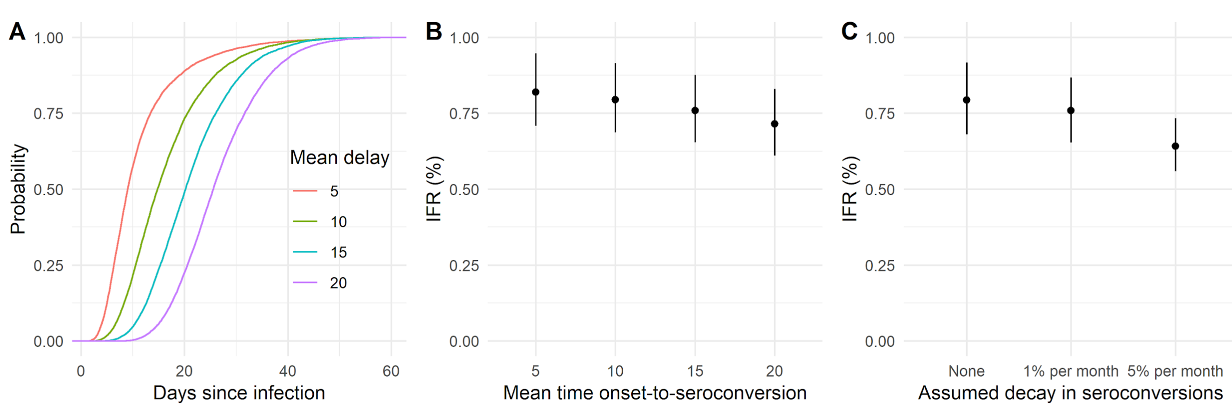


Figure S4. Sensitivity analyses regarding delays from infection-to-seroconversion and waning seropositivity over time. (A) Cumulative probability density functions for the delay between infection-to-seroconversion, obtained by varying the mean times from onset-to-seroconversion of 5, 10, 15 and 20 days. (B) Model estimates of the population IFR for France under different assumptions regarding the mean time from onset-to-seroconversion. (C) Model estimates of the population IFR for France under different assumed exponential decays in seroconversions over time (no decay, 1% decay per month and 5% decay per month).

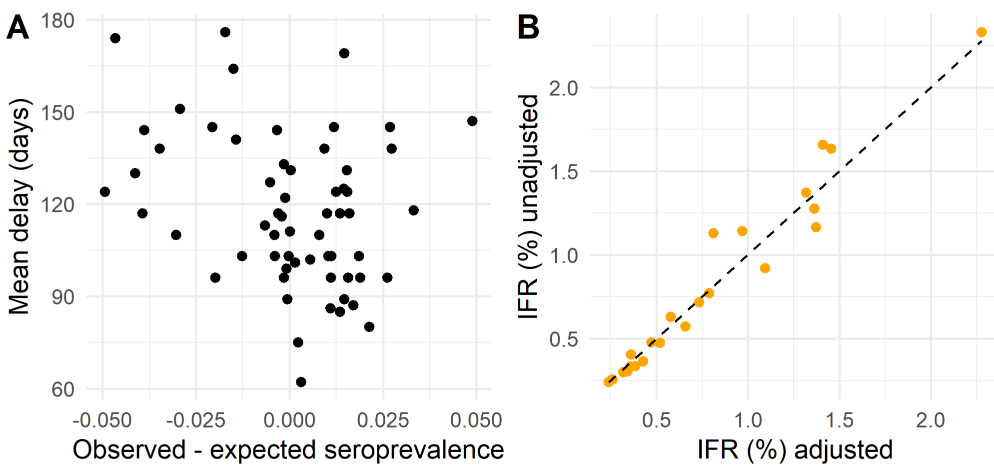


Figure S5. Seroprevalence data and IFR estimates. (A) Relationship between observed minus expected seroprevalence, as estimated by the ensemble model, with the mean delay from infection to time of seroprevalence sampling. (B) Median model estimates of France population IFR derived from separately fitting individual seroprevalence survey data adjusted and unadjusted for assay performance. Black dashed line represents values of x=y.

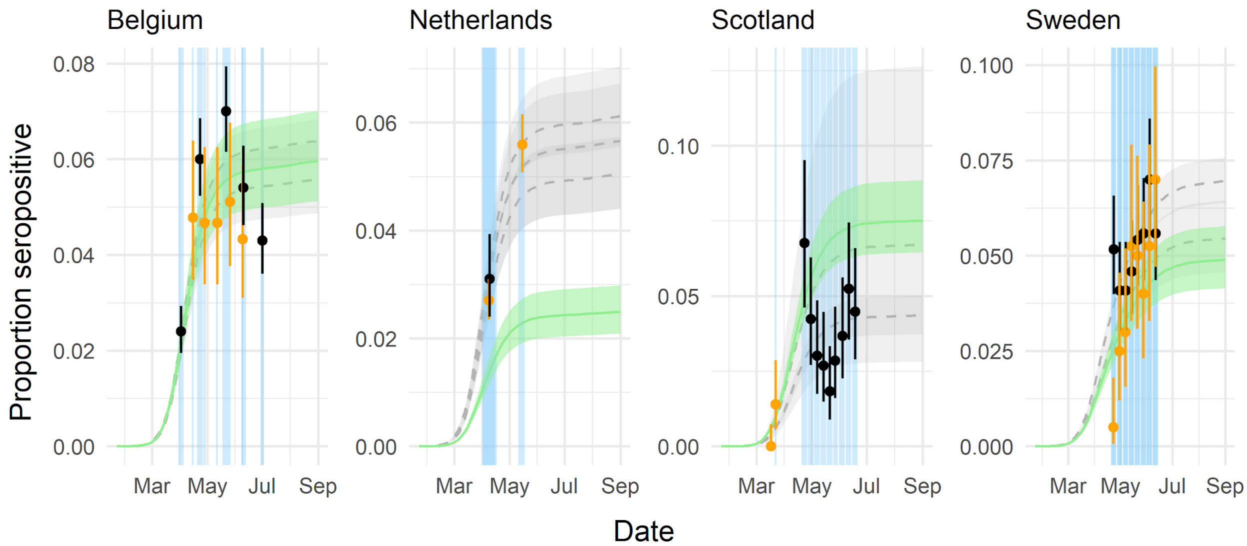


Figure S6. Blood Donor Serostudies. Estimated and reported seroprevalence over time in countries where both blood donor and general population seroprevalence surveys were conducted. Green line and ribbon indicate the median and 95% credible interval estimates of the ensemble model. Grey dashed lines and ribbons indicate the median and 95% credible interval model estimates derived from separately fitting to individual serostudies. Blue shading represents the timing of sampling of each reported seroprevalence estimate. Dots and lines show the mean and 95% binomial confidence intervals of the reported seroprevalence, where black represents studies conducted amongst the general population and orange represents studies conducted in blood donor samples.

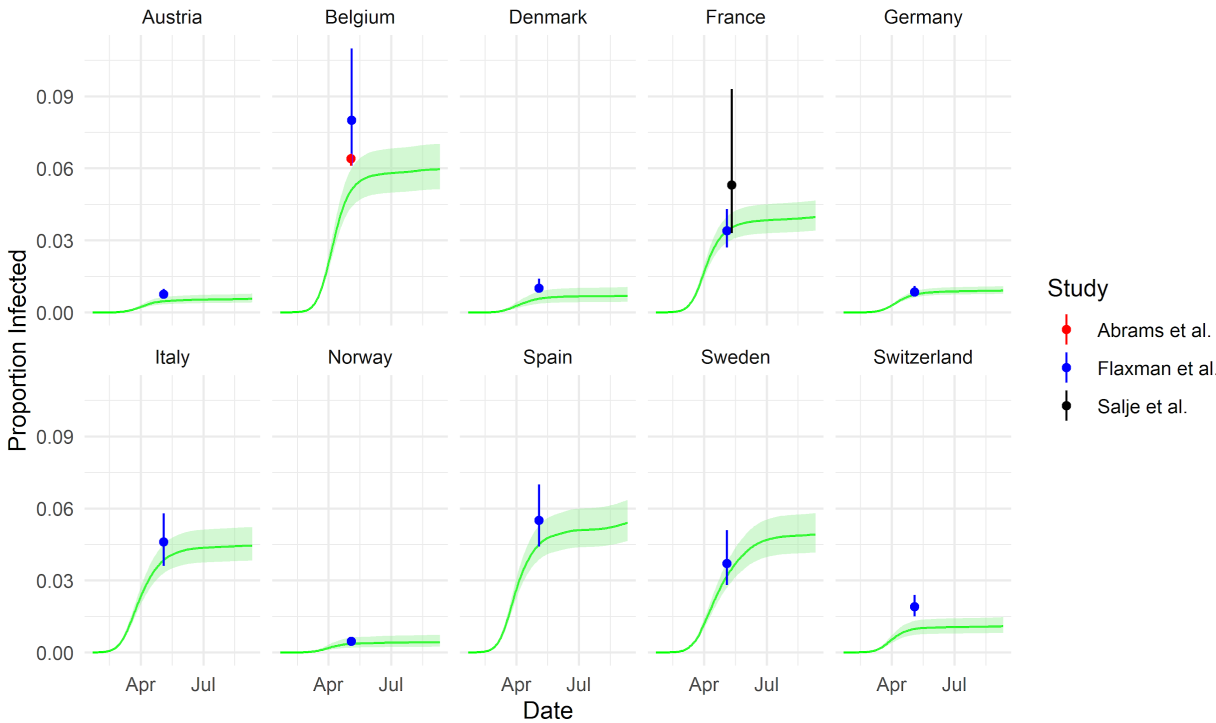


Figure S7. Infection estimate comparison. Comparison of ensemble model estimates of the proportion infected to those of other modelling efforts that use additional metrics of epidemic size[13,20,21]. Green lines and ribbons indicate the median and 95% credible interval estimates of the ensemble model. Coloured points and lines represent the central estimates and their associated uncertainty reported by external analyses.

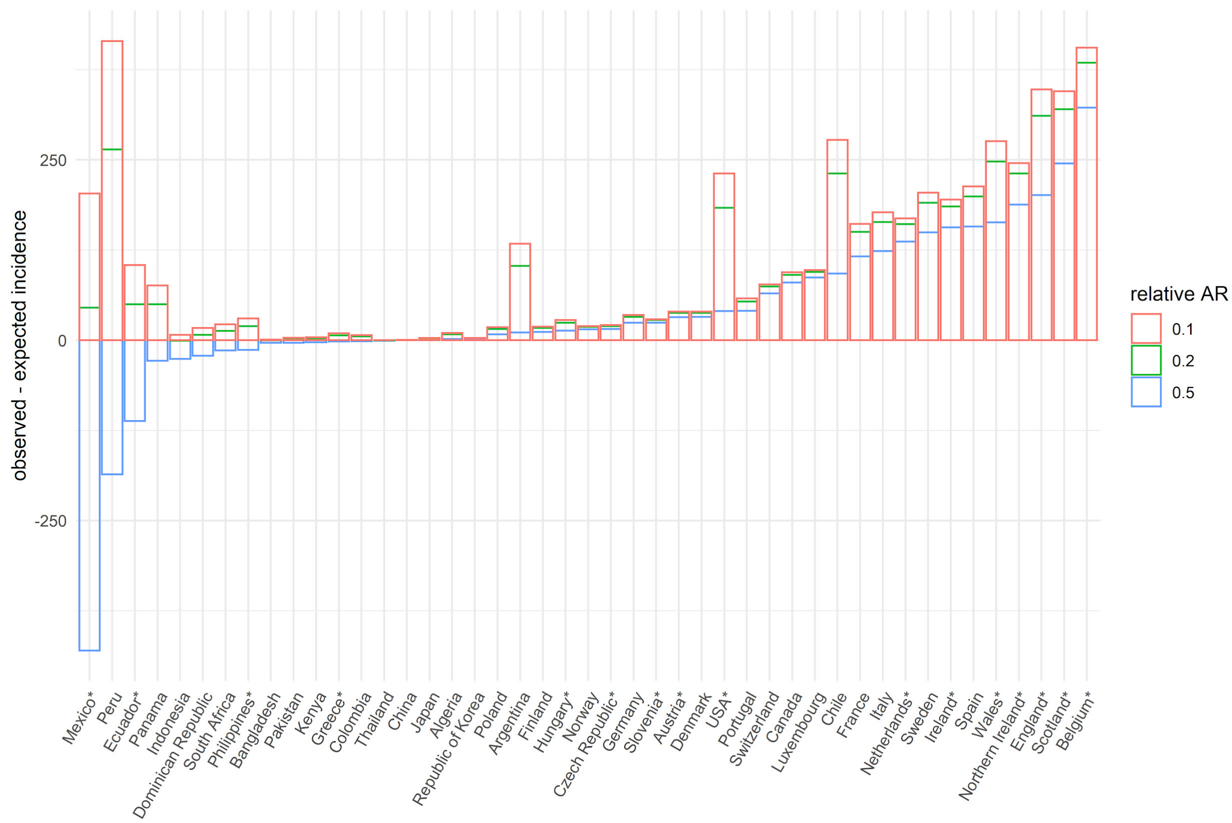


Figure S8. Varying attack rates in >65s. Observed minus expected incidence of deaths aged 60 or 65+, per 100,000 population, by country under different assumptions of the relative infection attack rate (AR) amongst over 65s.

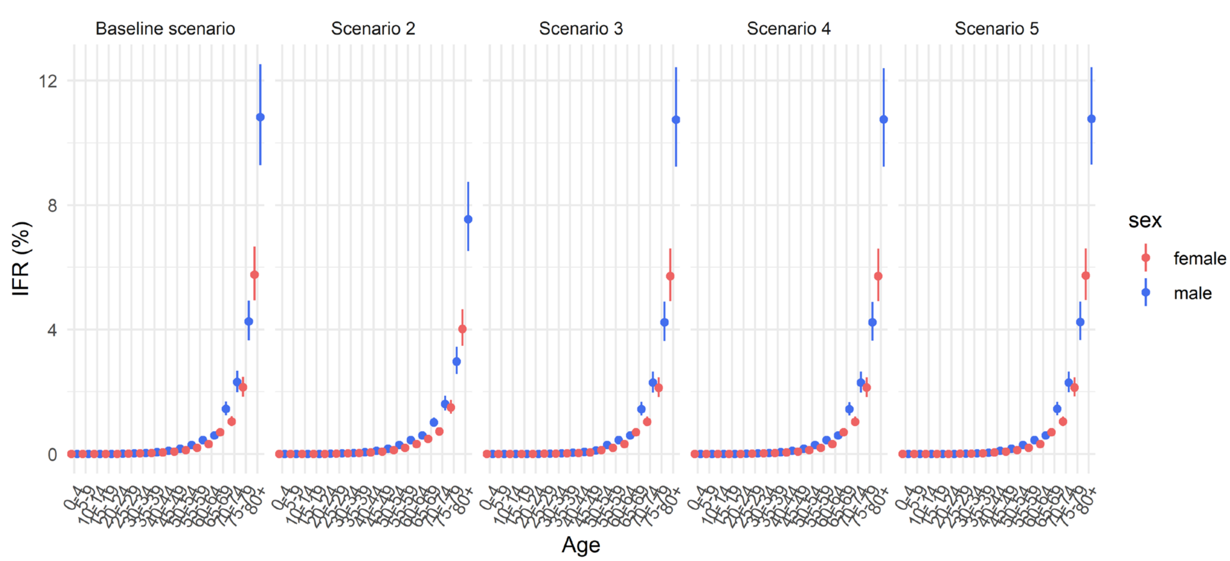


Figure S9. Age-specific attack rate sensitivity. Ensemble age- and sex-specific IFR estimates. Points and lines indicate median and 95% credible interval ensemble IFR estimates assuming equal attack rates amongst <65 year olds and a relative attack rate of 0.7 for individuals aged 65+ (baseline scenario); equal attack rates across all ages (scenario 2); relative attack rates of 1.5 for 20-40 year olds and 0.7 for 65+ (scenario 3); relative attack rates of 0.6 for 0-20 year olds and 0.7 for 65+ (scenario 4); and relative attack rates of 0.6 for 0-20 year olds, 1.5 for 20-40 year olds and 0.7 for 65+ (scenario 5).

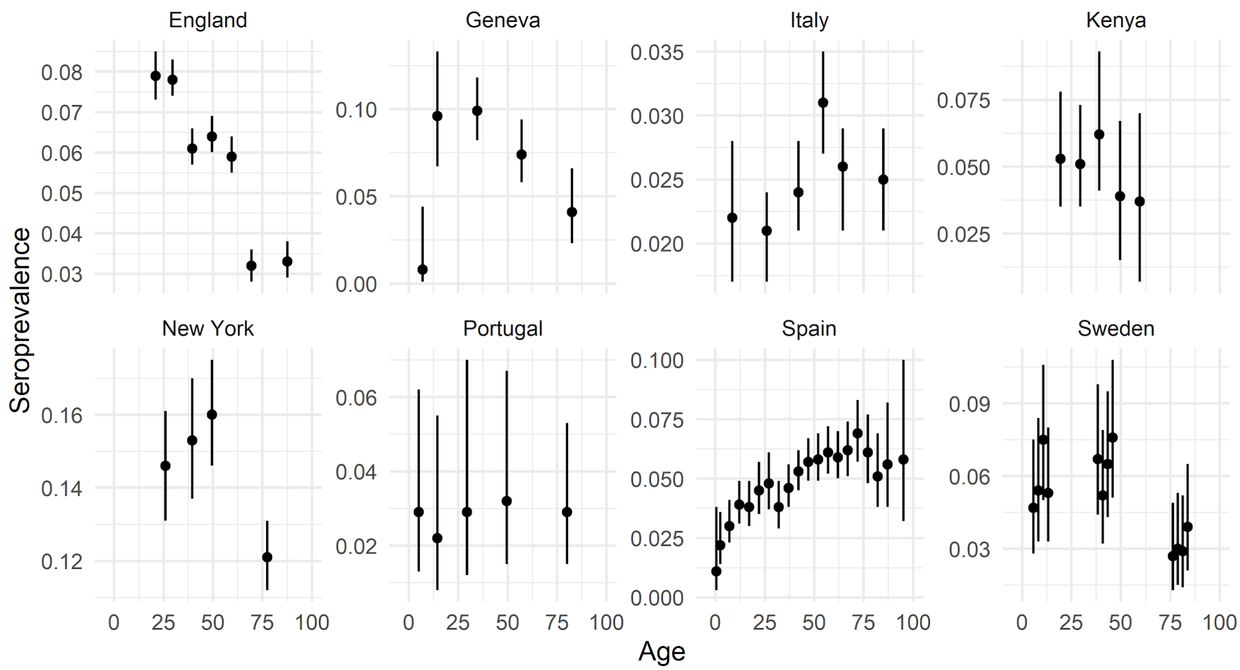


Figure S10. Age-specific seroprevalence data from 8 serostudies[7–9,42,46,47,52,57], plotted at the age-group mid-points.

Age Group	Male Median% (95%CrI) [Individual serostudy range]	Female Median% (95%CrI) [Individual serostudy range]	Mean Median% (95%CrI) [Individual serostudy range]
0-4	0.003 (0.002-0.004) [0.001-0.006]	0.003 (0.002-0.003) [0.001-0.005]	0.003 (0.002-0.003) [0.001-0.006]
5-9	0.001 (0.000-0.001) [0.000-0.001]	0.001 (0.000-0.001) [0.000-0.001]	0.001 (0.000-0.001) [0.000-0.001]
10-14	0.001 (0.001-0.002) [0.000-0.002]	0.001 (0.000-0.001) [0.000-0.001]	0.001 (0.001-0.001) [0.000-0.002]
15-19	0.003 (0.002-0.003) [0.001-0.005]	0.002 (0.002-0.003) [0.001-0.005]	0.003 (0.002-0.003) [0.001-0.005]
20-24	0.008 (0.007-0.009) [0.002-0.015]	0.005 (0.004-0.006) [0.002-0.010]	0.006 (0.005-0.008) [0.002-0.012]
25-29	0.017 (0.014-0.020) [0.005-0.032]	0.009 (0.008-0.011) [0.003-0.018]	0.013 (0.011-0.015) [0.004-0.025]

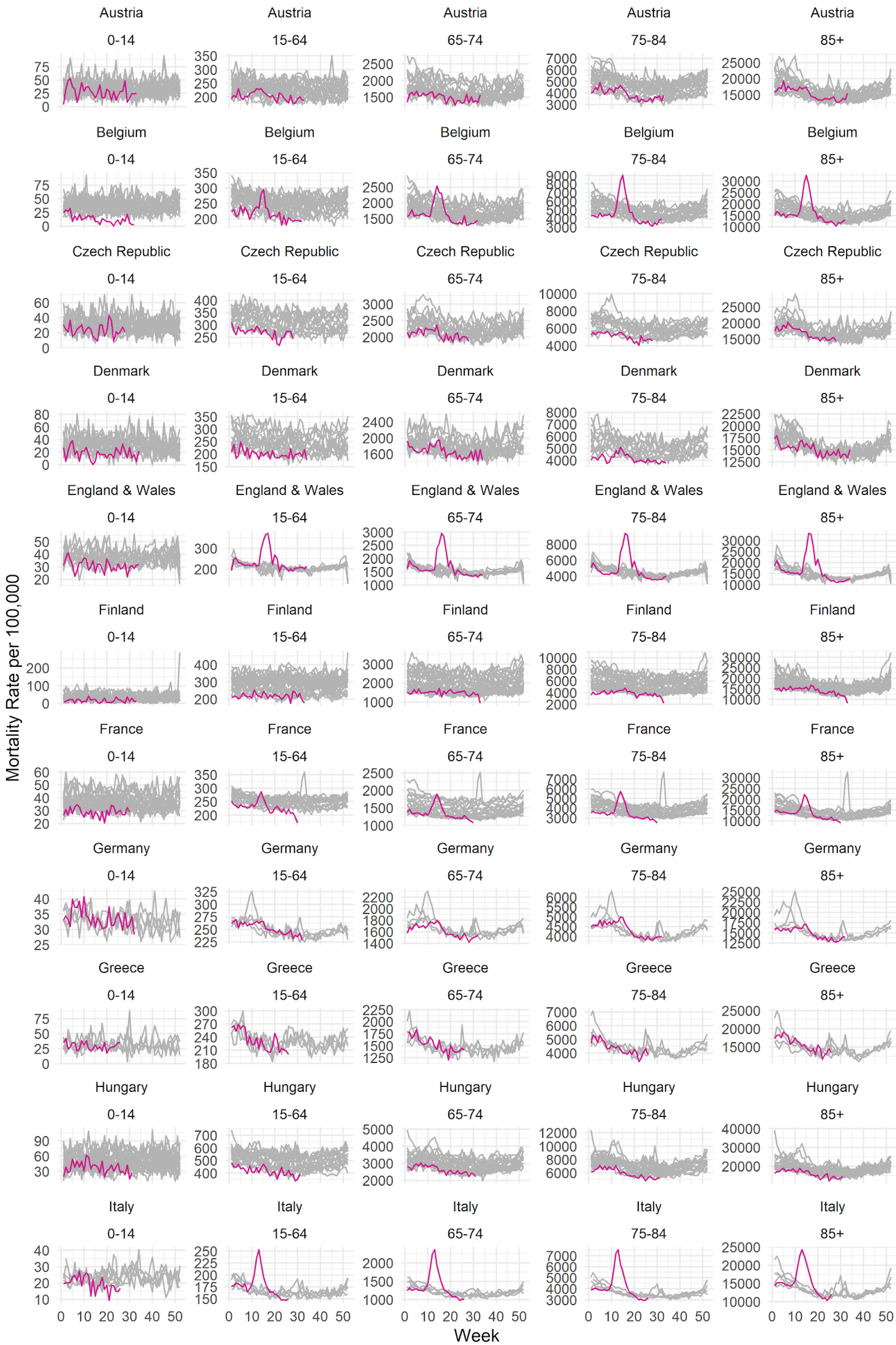
30-34	0.033 (0.028-0.038) [0.010-0.062]	0.015 (0.013-0.018) [0.005-0.030]	0.024 (0.021-0.028) [0.007-0.046]
35-39	0.056 (0.048-0.065) [0.017-0.105]	0.025 (0.021-0.029) [0.008-0.048]	0.040 (0.034-0.047) [0.012-0.077]
40-44	0.106 (0.091-0.123) [0.032-0.198]	0.044 (0.038-0.051) [0.013-0.083]	0.075 (0.064-0.087) [0.022-0.140]
45-49	0.168 (0.144-0.195) [0.050-0.315]	0.073 (0.063-0.085) [0.022-0.140]	0.121 (0.104-0.140) [0.036-0.227]
50-54	0.291 (0.250-0.336) [0.087-0.545]	0.123 (0.105-0.142) [0.037-0.231]	0.207 (0.177-0.239) [0.062-0.388]
55-59	0.448 (0.384-0.518) [0.134-0.838]	0.197 (0.169-0.228) [0.060-0.372]	0.323 (0.277-0.373) [0.097-0.605]
60-64	0.595 (0.511-0.688) [0.180-1.122]	0.318 (0.273-0.367) [0.096-0.598]	0.456 (0.392-0.527) [0.138-0.860]
65-69	1.452 (1.244-1.680) [0.436-2.723]	0.698 (0.598-0.807) [0.209-1.308]	1.075 (0.921-1.244) [0.323-2.016]
70-74	2.307 (1.976-2.668) [0.692-4.325]	1.042 (0.893-1.206) [0.313-1.954]	1.674 (1.435-1.937) [0.502-3.139]
75-79	4.260 (3.651-4.929) [1.279-7.988]	2.145 (1.838-2.482) [0.644-4.022]	3.203 (2.744-3.705) [0.961-6.005]
80+	10.825 (9.276-12.523) [3.249-20.297]	5.759 (4.935-6.662) [1.728-10.798]	8.292 (7.105-9.593) [2.488-15.547]

Table S3. Ensemble model age- and sex-specific infection fatality ratio estimates and the respective ranges suggested by individual national-level seroprevalence surveys.

Country	**Median% (95%CrI) [Individual serostudy range]**
Algeria	2.19% (1.78-2.71%) [1.17-7.34]
Argentina	10.51% (9.06-12.31%) [5.62-35.05]
Austria	0.56% (0.40-0.77%) [0.30-1.87]
Bangladesh	4.18% (3.50-5.03%) [2.22-13.86]
Belgium	5.96% (5.12-7.01%) [3.15-19.66]
Canada	1.40% (1.16-1.68%) [0.74-4.64]
Chile	18.94% (16.29-22.23%) [10.06-63.12]
China	0.09% (0.08-0.11%) [0.05-0.31]
Colombia	25.39% (20.91-30.96%) [13.48-84.55]
Czech Republic	0.46% (0.32-0.64%) [0.24-1.51]

Denmark	0.69% (0.43-1.05%) [0.28-1.76]
Dominican Republic	16.25% (13.23-19.97%) [8.51-53.51]
Ecuador	44.72% (38.48-52.40%) [23.84-149.16]
England	10.97% (9.48-12.80%) [5.85-36.56]
Finland	0.68% (0.43-1.00%) [0.31-1.91]
France	3.95% (3.38-4.63%) [2.10-13.12]
Germany	0.90% (0.76-1.08%) [0.48-3.02]
Greece	0.65% (0.49-0.86%) [0.36-2.18]
Hungary	1.18% (0.92-1.5%) [0.63-3.93]
Indonesia	4.03% (3.48-4.70%) [2.16-13.44]
Ireland	3.12% (2.46-3.94%) [1.65-10.30]
Italy	4.45% (3.82-5.21%) [2.37-14.79]
Japan	0.10% (0.07-0.13%) [0.05-0.33]
Kenya	2.36% (1.90-2.91%) [1.24-12.89]
Luxembourg	0.99% (0.31-2.26%) [0.39-2.29]
Mexico	49.58% (42.92-57.76%) [26.34-164.45]
Netherlands	2.49% (2.09-2.98%) [1.31-8.14]
Northern Ireland	4.31% (3.22-5.72%) [2.29-14.35]
Norway	0.43% (0.23-0.73%) [0.23-1.42]
Pakistan	3.94% (3.35-4.68%) [2.10-13.07]
Panama	31.45% (25.65-38.44%) [16.69-104.53]
Peru	62.44% (54.07-72.90%) [33.13-207.20]
Philippines	3.71% (3.19-4.34%) [1.93-12.24]
Poland	1.04% (0.85-1.27%) [0.56-3.47]
Portugal	1.48% (1.15-1.90%) [0.78-4.85]
Republic of Korea	0.06% (0.04-0.09%) [0.03-0.21]
Scotland	7.51% (6.45-8.85%) [4.35-27.23]
Slovenia	0.34% (0.14-0.67%) [0.15-0.93]
South Africa	28.35% (24.31-33.34%) [15.09-94.01]
Spain	5.33% (4.58-6.27%) [2.83-17.72]
Sweden	4.90% (4.15-5.78%) [2.41-15.11]
Switzerland	1.09% (0.81-1.46%) [0.58-3.61]
Thailand	0.08% (0.05-0.11%) [0.04-0.26]
USA	14.37% (12.44-16.77%) [7.64-47.77]
Wales	8.67% (7.13-10.59%) [4.61-28.69]

Table S4. Ensemble model estimates of infected population proportions as of the 1st of September 2020 and the respective ranges suggested by individual national-level seroprevalence surveys.


Austria 0-14
Austria 15-64
Austria 65-74
Austria 75-84
Austria 85+
Belgium 0-14
Belgium 15-64
Belgium 65-74
Belgium 75-84
Belgium 85+
Czech Republic 0-14
Czech Republic 15-64
Czech Republic 65-74
Czech Republic 75-84
Czech Republic 85+
Denmark 0-14
Denmark 15-64
Denmark 65-74
Denmark 75-84
Denmark 85+
England & Wales 0-14
England & Wales 15-64
England & Wales 65-74
England & Wales 75-84
England & Wales 85+
Finland 0-14
Finland 15-64
Finland 65-74
Finland 75-84
Finland 85+
France 0-14
France 15-64
France 65-74
France 75-84
France 85+
Germany 0-14
Germany 15-64
Germany 65-74
Germany 75-84
Germany 85+
Greece 0-14
Greece 15-64
Greece 65-74
Greece 75-84
Greece 85+
Hungary 0-14
Hungary 15-64
Hungary 65-74
Hungary 75-84
Hungary 85+
Italy 0-14
Italy 15-64
Italy 65-74
Italy 75-84
Italy 85+
Mortality Rate per 100,000
0 10 20 30 40 50
Week

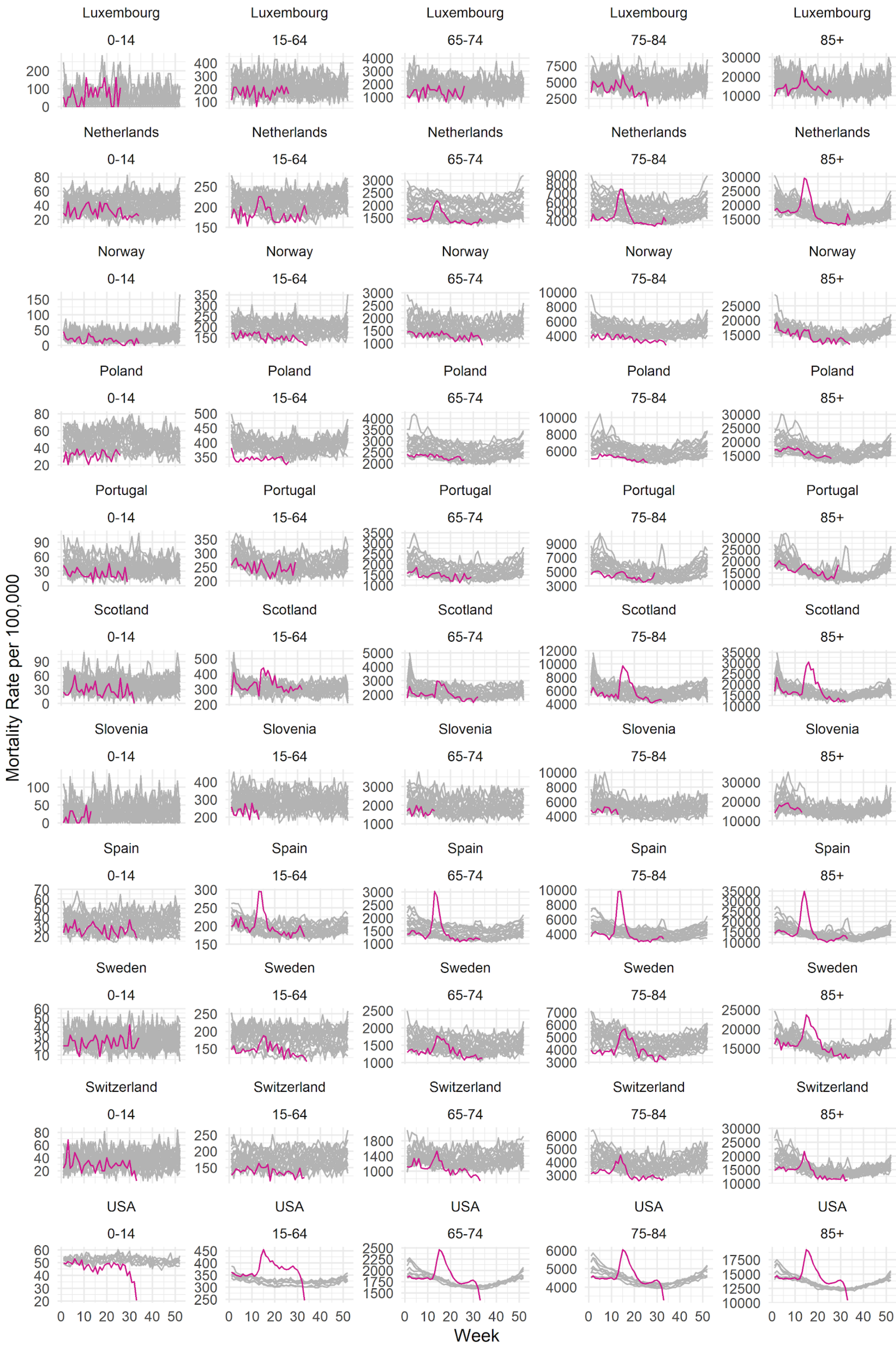

Luxembourg 0-14
Luxembourg 15-64
Luxembourg 65-74
Luxembourg 75-84
Luxembourg 85+
Netherlands 0-14
Netherlands 15-64
Netherlands 65-74
Netherlands 75-84
Netherlands 85+
Norway 0-14
Norway 15-64
Norway 65-74
Norway 75-84
Norway 85+
Poland 0-14
Poland 15-64
Poland 65-74
Poland 75-84
Poland 85+
Portugal 0-14
Portugal 15-64
Portugal 65-74
Portugal 75-84
Portugal 85+
Scotland 0-14
Scotland 15-64
Scotland 65-74
Scotland 75-84
Scotland 85+
Slovenia 0-14
Slovenia 15-64
Slovenia 65-74
Slovenia 75-84
Slovenia 85+
Spain 0-14
Spain 15-64
Spain 65-74
Spain 75-84
Spain 85+
Sweden 0-14
Sweden 15-64
Sweden 65-74
Sweden 75-84
Sweden 85+
Switzerland 0-14
Switzerland 15-64
Switzerland 65-74
Switzerland 75-84
Switzerland 85+
USA 0-14
USA 15-64
USA 65-74
USA 75-84
USA 85+
0 10 20 30 40 50
Mortality Rate per 100,000
Week

Figure S11. Age-specific mortality rates per 100,000 population in 22 countries from the Human Mortality Database[64]. Grey lines indicate weekly mortality rates for all available years prior to 2020 and the red line represents weekly mortality rates in 2020.

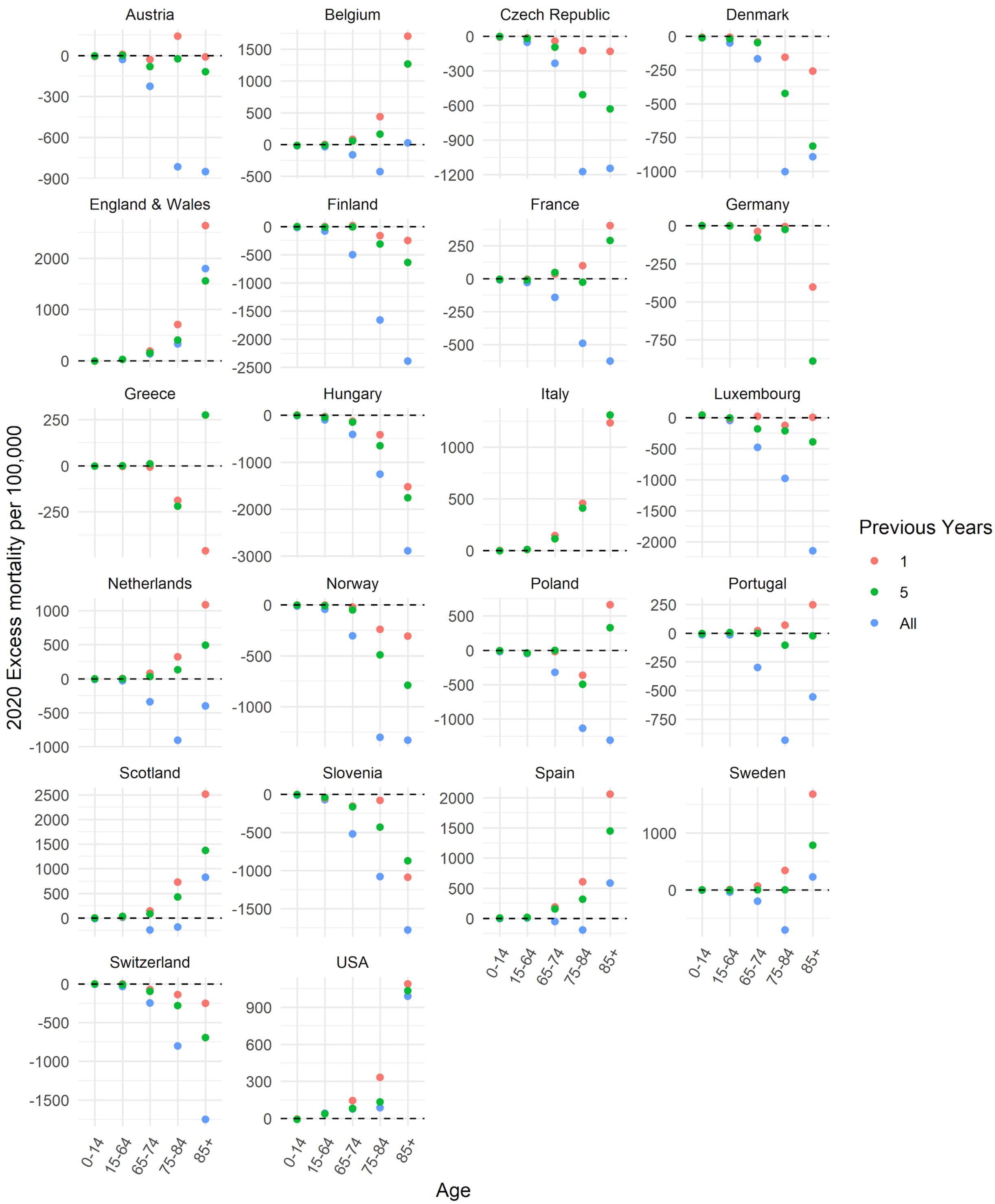


Figure S12. Age-specific excess mortality in 2020 as compared to the average of previous years for the same time period[64]. Coloured points show mortality rates as compared to the same time period in 2019 (coral), 2015-2019 (green) and all previous years (blue). Black dashed lines indicate values of zero excess deaths.

References:

1. Pastor-Barriuso, R. *et al.* SARS-CoV-2 infection fatality risk in a nationwide seroepidemiological study. *medRxiv* (2020).
2. Verity, R. *et al.* Estimates of the severity of coronavirus disease 2019: a model-based analysis. *Lancet Infect. Dis.* **20**, 669–677 (2020).
3. Comas-Herrera, A., Zalakain, J., Litwin, C., T Hsu, A. & Fernandez-Plotka, J.-L. Resources to support community and institutional Long-Term Care responses to COVID-19. (2020).
4. Guan, W.-J. *et al.* Clinical Characteristics of Coronavirus Disease 2019 in China. *N. Engl. J. Med.* **382**, 1708–1720 (2020).
5. Clark, A. *et al.* Global, regional, and national estimates of the population at increased risk of severe COVID-19 due to underlying health conditions in 2020: a modelling study. *Lancet Glob Health* **8**, e1003–e1017 (2020).
6. Comas-Herrera, A. *et al.* Mortality associated with COVID-19 outbreaks in care homes: early international evidence. *LTCcovid. org, International Long-Term Care Policy Network* (2020).
7. Pollán, M. *et al.* Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study. *Lancet* (2020) doi:10.1016/S0140-6736(20)31483-5.
8. Stringhini, S. *et al.* Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based study. *Lancet* **396**, 313–319 (2020).
9. Rosenberg, E. S. *et al.* Cumulative incidence and diagnosis of SARS-CoV-2 infection in New York. *Ann. Epidemiol.* **48**, 23-29.e4 (2020).
10. Herzog, S. *et al.* Seroprevalence of IgG antibodies against SARS coronavirus 2 in Belgium: a prospective cross-sectional study of residual samples. *medRxiv* (2020).
11. Takahashi, S., Greenhouse, B. & Rodríguez-Barraquer, I. Are SARS-CoV-2 seroprevalence estimates biased? (2020).
12. Prem, K., Cook, A. R. & Jit, M. Projecting social contact matrices in 152 countries using contact surveys and demographic data. *PLoS Comput. Biol.* **13**, e1005697 (2017).

13. Salje, H. *et al.* Estimating the burden of SARS-CoV-2 in France. *Science* **369**, 208–211 (2020).
14. Jin, J.-M. *et al.* Gender Differences in Patients With COVID-19: Focus on Severity and Mortality. *Front Public Health* **8**, 152 (2020).
15. Huang, A. T. *et al.* A systematic review of antibody mediated immunity to coronaviruses: kinetics, correlates of protection, and association with severity. *Nat. Commun.* **11**, 4704 (2020).
16. Braun, J. *et al.* SARS-CoV-2-reactive T cells in healthy donors and patients with COVID-19. *Nature* (2020) doi:10.1038/s41586-020-2598-9.
17. Buss, L. F. *et al.* COVID-19 herd immunity in the Brazilian Amazon. *medRxiv* (2020).
18. Antonio, C. A. A. *et al.* Seroprevalencia de anticuerpos anti SARS-CoV-2 en la ciudad de Iquitos, Loreto, Perú. https://docs.google.com/document/d/1K-aKyFmxztdfNJOtXuSH1uGcBeaZA7LH/edit.
19. Del Brutto, O. H. *et al.* SARS-CoV-2 in rural Latin America. A population-based study in coastal Ecuador. *Clin. Infect. Dis.* (2020) doi:10.1093/cid/ciaa1055.
20. Flaxman, S. *et al.* Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. *Nature* (2020) doi:10.1038/s41586-020-2405-7.
21. Abrams, S. *et al.* Modeling the early phase of the Belgian COVID-19 epidemic using a stochastic compartmental model and studying its implied future trajectories. *medRxiv* (2020).
22. Fontanet, A. & Cauchemez, S. COVID-19 herd immunity: where are we? *Nat. Rev. Immunol.* **20**, 583–584 (2020).
23. Molenberghs, G. *et al.* Belgian Covid-19 Mortality, Excess Deaths, Number of Deaths per Million, and Infection Fatality Rates (8 March - 9 May 2020). doi:10.1101/2020.06.20.20136234.
24. Soveri, H. *et al.* Why, in almost all countries, was residential care for older people so badly affected by COVID-19?
25. Hardy, O. J. *et al.* A world apart: levels and factors of excess mortality due to COVID-19 in care homes. The case of Wallonia-Belgium. *medRxiv* (2020).
26. Aron, J., Giattino, C., Muellbauer, J. & Ritchie, H. A pandemic primer on excess mortality statistics and their comparability across countries. *Accessed August* **19**, 2020 (2020).

27. Dong, E., Du, H. & Gardner, L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect. Dis.* **20**, 533–534 (2020).
28. De Wulf, M. Population Pyramids of the World from 1950 to 2100. (2016).
29. World Population Prospects - Population Division - United Nations. https://population.un.org/wpp/.
30. Caul, S. Deaths registered weekly in England and Wales, provisional. (2020).
31. Wu, J. T. *et al.* Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China. *Nat. Med.* **26**, 506–510 (2020).
32. Backer, J. A., Klinkenberg, D. & Wallinga, J. Incubation period of 2019 novel coronavirus (2019-nCoV) infections among travellers from Wuhan, China, 20-28 January 2020. *Euro Surveill.* **25**, (2020).
33. Lou, B. *et al.* Serology characteristics of SARS-CoV-2 infection since exposure and post symptom onset. *Eur. Respir. J.* (2020) doi:10.1183/13993003.00763-2020.
34. Wu, J. T. *et al.* The infection attack rate and severity of 2009 pandemic H1N1 influenza in Hong Kong. *Clin. Infect. Dis.* **51**, 1184–1191 (2010).
35. Stan Development Team. RStan: the R interface to Stan. *R package version* **2**, (2016).
36. Herzog, S. *et al.* Seroprevalence of IgG antibodies against SARS coronavirus 2 in Belgium: a serial prospective cross-sectional nationwide study of residual samples. *Epidemiology* (2020) doi:10.1101/2020.06.08.20125179.
37. Nouveau Coronavirus (Maladie: COVID-19, Virus: SARS-CoV-2). https://covid-19.sciensano.be/fr.
38. Infekce covid-19 prošla českou populací velmi mírně, podobně jako v okolních zemích – Aktuální informace o COVID-19. https://koronavirus.mzcr.cz/infekce-covid-19-prosla-ceskou-populaci-velmi-mirne-podobne-jako-v-okolnich-zemich/.
39. Coronavirus: Som bloddonor hjælper du nu med at afdække det danske mørketal - Bloddonorerne i Danmark. https://bloddonor.dk/coronavirus/.
40. Erikstrup, C. *et al.* Estimation of SARS-CoV-2 infection fatality rate by real-time antibody screening of blood donors. *Clin. Infect. Dis.* (2020) doi:10.1093/cid/ciaa849.

41. Emily Connors And. Coronavirus (COVID-19) Infection Survey pilot - Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/18june2020 (2020).
42. Ward, H. *et al.* Antibody prevalence for SARS-CoV-2 in England following first peak of the pandemic: REACT2 study in 100,000 adults. *medRxiv* 2020.08.12.20173690 (2020) doi:10.1101/2020.08.12.20173690.
43. Koronaepidemian väestöserologiatutkimuksen viikkoraportti. https://www.thl.fi/roko/cov-vaestoserologia/sero_report_weekly.html.
44. Infection à coronavirus. https://www.santepubliquefrance.fr/maladies-et-traumatismes/maladies-et-infections-respiratoires/infection-a-coronavirus.
45. Merkely, B. *et al.* Novel coronavirus epidemic in the Hungarian population, a cross-sectional nationwide survey to support the exit policy in Hungary. *Geroscience* **42**, 1063–1074 (2020).
46. Primi risultati dell'indagine di sieroprevalenza sul SARS-CoV-2. https://www.istat.it/it/archivio/246156 (2020).
47. Uyoga, S. *et al.* Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Kenyan blood donors. *Infectious Diseases (except HIV/AIDS)* (2020) doi:10.1101/2020.07.27.20162693.
48. Snoeck, C. J. *et al.* Prevalence of SARS-CoV-2 infection in the Luxembourgish population: the CON-VINCE study. *Infectious Diseases (except HIV/AIDS)* (2020) doi:10.1101/2020.05.11.20092916.
49. Slot, E. *et al.* Herd immunity is not a realistic exit strategy during a COVID-19 outbreak. *In Review* (2020) doi:10.21203/rs.3.rs-25862/v1.
50. Children, school and COVID-19. https://www.rivm.nl/en/novel-coronavirus-covid-19/children-and-covid-19.
51. van den Hurk, K. *et al.* Low awareness of past SARS-CoV-2 infection in healthy adults. *Epidemiology* (2020) doi:10.1101/2020.08.10.20171561.

52. Inquérito Serológico Nacional COVID-19 indica seroprevalência de 2,9% de infeção por SARS-CoV-2 em Portugal - INSA. http://www.insa.min-saude.pt/inquerito-serologico-nacional-covid-19-indica-seroprevalencia-de-29-de-infecao-por-sars-cov-2-em-portugal/.
53. Amorim Filho, L. *et al.* Seroprevalence of IgG and IgM anti-SARS-CoV-2 among voluntary blood donors in Rio de Janeiro, Brazil. (2020) doi:10.1590/SciELOPreprints.404.
54. Thompson, C. P. *et al.* Detection of neutralising antibodies to SARS coronavirus 2 to determine population exposure in Scottish blood donors between March and May 2020. *Infectious Diseases (except HIV/AIDS)* (2020) doi:10.1101/2020.04.13.20060467.
55. Enhanced Surveillance of COVID-19 in Scotland. https://beta.isdscotland.org/find-publications-and-data/population-health/covid-19/enhanced-surveillance-of-covid-19-in-scotland/.
56. Maver Vodičar, P. *et al.* Low prevalence of active COVID-19 in Slovenia: a nationwide population study of a probability-based sample. *Clin. Microbiol. Infect.* (2020) doi:10.1016/j.cmi.2020.07.013.
57. Undersökningar och datainsamlingar. https://www.folkhalsomyndigheten.se/smittskydd-beredskap/utbrott/aktuella-utbrott/covid-19/statistik-och-analyser/undersokningar-och-datainsamlingar/.
58. Situation update on coronavirus - Infectious diseases and vaccinations - THL. https://thl.fi/en/web/infectious-diseases/what-s-new/coronavirus-covid-19-latest-updates/situation-update-on-coronavirus.
59. etalab-covid19-dashboard. https://dashboard.covid19.data.gouv.fr/vue-d-ensemble?location=FRA.
60. DEATHS REGISTERED - DASHBOARD. https://files.nisra.gov.uk/Deaths/Weekly-Deaths-Dashboard.html.
61. Coronaviruset: Slik spres viruset i Norge og verden. Kart og statistikk. https://www.vg.no/spesial/2020/corona/.
62. National Records of Scotland Web Team. National Records of Scotland. (2013).
63. Moor, A., Brupbacher, M., Balmer, D. & Plattner, T. Mehr als die Hälfte der Corona-Toten starb in Alters- und Pflegeheimen. *Tamedia AG* https://interaktiv.tagesanzeiger.ch/2020/corona-tote-

mehrheitlich-aus-altersheimen/ (2020).

64. Human Mortality Database. https://www.mortality.org/.