EXTENDED SUPPLEMENTAL INFORMATION

COVID-19 and All-Cause Mortality in the US and 18 Comparison Countries

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CALCULATIONS IN TABLES 1 AND 2

Difference in deaths

Let r_i be the death rate of interest (reported COVID-19 deaths or excess all cause mortality) per 100,000 in country i, and d be US deaths over the period of study. Let p be the US 2019 population, $p = 329,064,917$ according to the European Centre for Disease Prevention and Control. We estimate difference in deaths:

$$d - (r_i/100,000) * p \tag{1}$$

Difference in deaths if comparable after some time point

Letting r_{iT} be the death rate per 100,000 in country i between time T and the end of the period of study and d_T be US deaths by time T, we estimate potential difference in deaths since time T:

$$d - (d_T + (r_{iT}/100,000) * p) \tag{2}$$

Difference in deaths if matching after some criteria is met (i.e., adjustment for pandemic timing)

Let time T_i be the time that country i meets some criteria (e.g., 60 days after ≥ 1 case per 1,000,000 population). Let T be the time that the US meets the criteria. Letting r_{iT_i} be the death rate per 100,000 in a comparison country between time T_i and the end of the reporting period and d_T be US deaths until time T, we estimate potential difference in deaths since time T:

$$d - \left(d_T + \left(r_{iT_i}/100,000\right) * p\right) \tag{3}$$

TECHNICAL NOTES

Analytic approach

1. There has been debate in the epidemiological community regarding whether focus on total deaths or deaths per capita early in the pandemic. Given a fixed number introductions, we do not expect that early in a pandemic, a virus would spread faster in a larger population than in a smaller one. Nevertheless, we defer to per capita measures due to the geographic and demographic diversity of the United States that renders it likely more similar to a combination of small countries than a single countries, and as viral introductions may be proportional to population, especially over time. In addition, this measure may better capture the pandemic's relative impact in terms of general perceptions and disruption.
2. Due to large sample sizes, traditional statistical inference around differences in mortality rates often have narrow confidence intervals and meets traditional standards for "statistical significance" (see e.g., Weinberger et. al). As our other outcome measures (e.g. excess deaths) are invertible monotone transformation of mortality rates, statistical conclusions about the former apply to the latter. However, other sources of uncertainty affect our results more than statistical randomness, as we show in sensitivity analyses.
3. Our main analyses focus on *calendar time*, assessing the difference in deaths if the US death rate became comparable to another country's death rate after a particular time. We consider both May and June for this shift, allowing 1-2 months for policy response beginning in March and assuming $\sim$ 1 month to

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[2]Data and code are available on GitHub (link).

death from exposure. We use calendar time as our main specification because 1) the pandemic affected most countries at similar times (Table S1), and 2) to the extent that there were differences, countries were able to react to the experiences of peer countries (e.g. by responding earlier even if the pandemic affected them later). However, we may want to *adjust for pandemic timing* if, for example, countries were unable to gain political will to implement measures before evidence of a more local pandemic and/or if the pandemic was particularly difficult to control until cases reached a specific threshold. We therefore considered 2 sensitivity analyses in (Table S1, S2, S3): 1) assuming the US had a comparable mortality rate to a country 60 days after reaching 1 case per million (Scenario D) and 2) assuming the US had a comparable mortality rate to a country 60 days after reaching 5 deaths (Scenario E). The former estimates fewer deaths averted than May estimates while the latter estimates more.

4. For excess all-cause mortality, we use 2015-2019 as comparison years by default, based on the CDC's excess death estimates. In sensitivity analysis, we also presented results using 2018-2019 (Table S3), which has a slightly lower estimate of excess all-cause mortality (217K vs. 235K) but similar overall comparisons across countries.

Country-level data

1. Spain adjusted its cumulative COVID-19 death toll downward (and then partially upward) during May and June 2020. We smoothed this to be monotonic over this time period by setting cumulative deaths between May 23, 2020 and June 18, 2020 to be equal to the reported death toll on June 19, 2020 (Figure 1).
2. For recent periods in which some deaths may not yet have been reported, the United States CDC provides estimates of both unweighted deaths and deaths weighted to attempt to adjust for underreporting. To be conservative in our estimate of excess deaths, we use the latter (Figure 2). In our excess all-cause mortality analyses, we use through week 30 (July 25, 2020). While difficult to pinpoint a precise cut-off at which data were sufficiently complete for inclusion, both CDC reported deaths and COVID-19 attributed deaths (see "USA_2.csv") began to decline through August despite increases in deaths from COVID Tracking Project, suggesting ddelays in reporting by at least week 32-33. Week 30 was also the last time point at which data were available for Canada, allowing us to include the country our excess all-cause mortality analysis.
3. Several countries reported lower than average all-cause mortality in 2020 prior to the pandemic (Figure 3). For this reason, we start measurement of all-cause mortality after the pandemic began in a country ($\geq$ 1 case per million, generally week 9-10).
4. We lacked sufficient data from Australia, Japan, and South Korea to do direct comparisons in our excess deaths analysis (Table 2 of main paper), but analyses of available data suggest that these low mortality countries did not experience meaningful excess mortality during 2020 (e.g. Australia, Japan, South Korea)
5. France provided a file of estimated deaths beginning in February for the years 2018-2020. Following *The Economist* GitHub, we used France's death registers to fill in 2015-2017. When we compared the death registers in 2018 to the first file, we found that the latter had lower deaths by week, and therefore to be conservative in estimates of excess deaths and following the approach of *The Economist*, we only included deaths with a valid department code in "location of death."

Other

1. Research letters are limited to 6 references, and cited papers must be peer-reviewed. However, there were a number of other sources consulted, including on the potential impact of early interventions prior to a US surge (Pei et. al., NYT, StatNews); on excess mortality (*News:* Economist, NYT, Our World in Data, Nature News; *Academic:* Aron and Muellbauer, Weinberger et. al, Woolf et. al, Stokes et. al.). Similar issues were also debated recently in NYT (link, link) and in Vox.

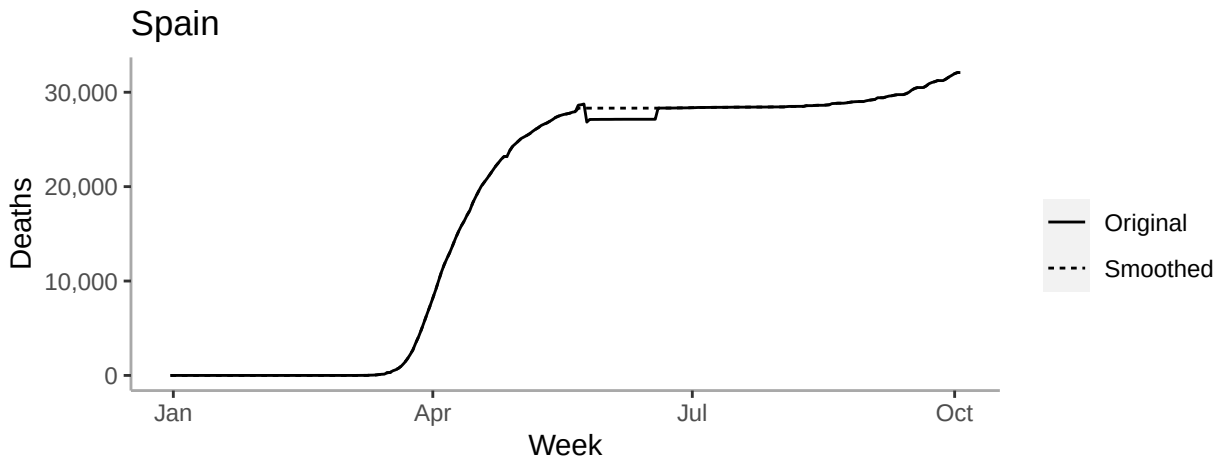

Figure 1 – Spanish COVID-19 deaths, with and without smoothing.

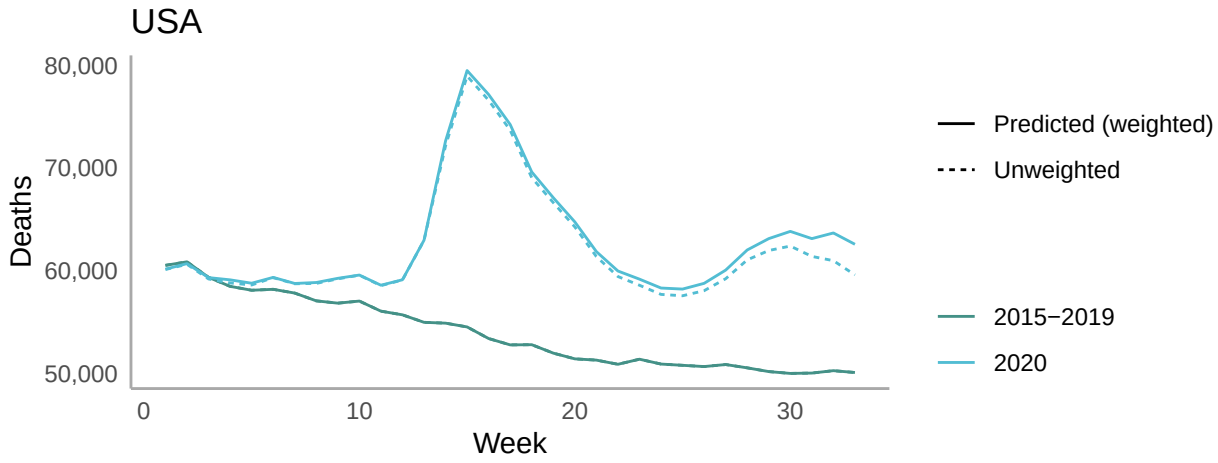

Figure 2 – Deaths by week with and without weighting for underreporting. The line marked 2015-2019 represented the average over those years.

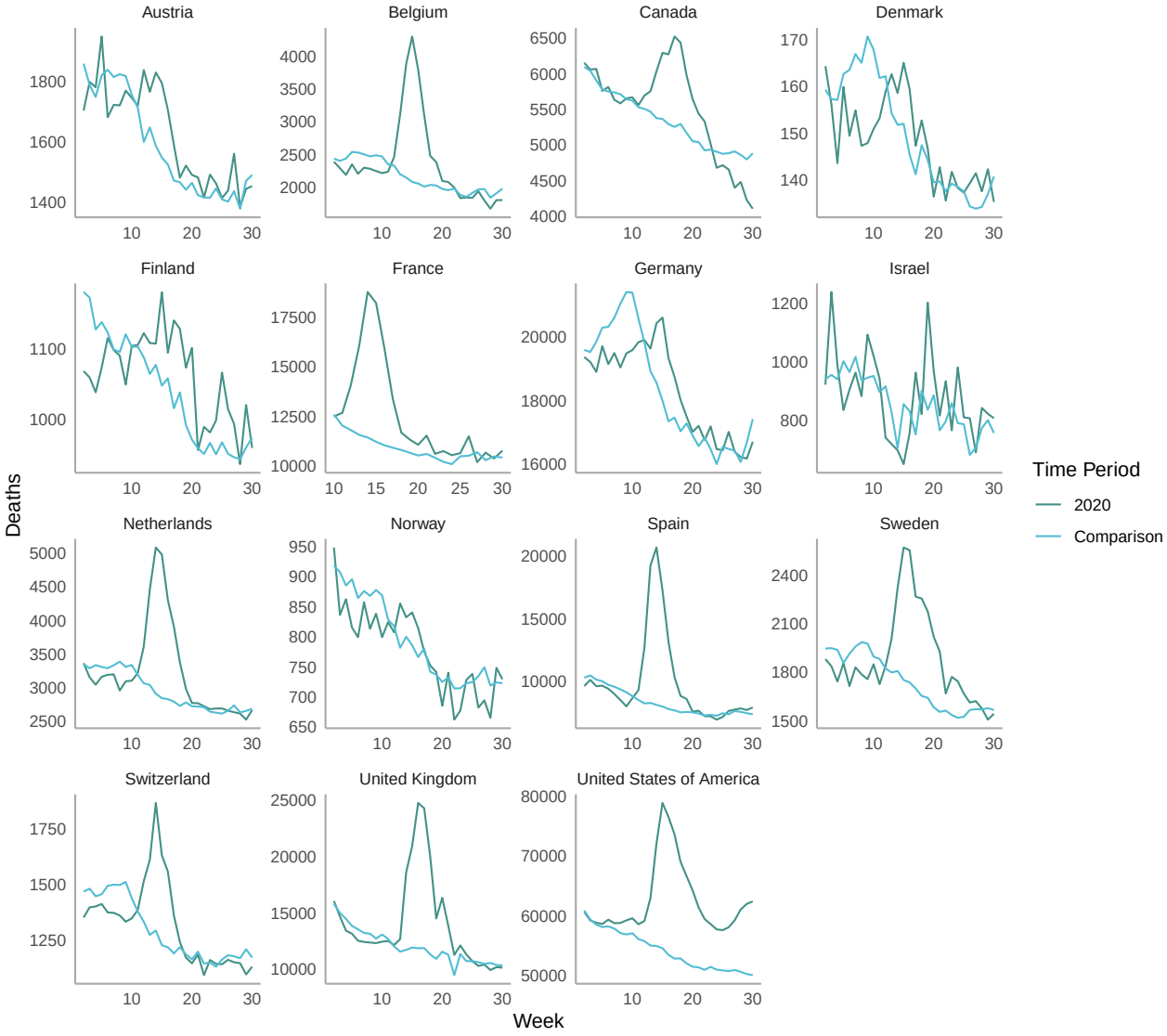

Figure 3 – All-cause mortality by country by week and year. The comparison period is the average of 2015-2019, except in Germany, we used only years 2016-19 due data accessibility. Early 2020 mortality is lower than average in e.g. Denmark, Germany, and Switzerland.

MORTALITY TIME SERIES

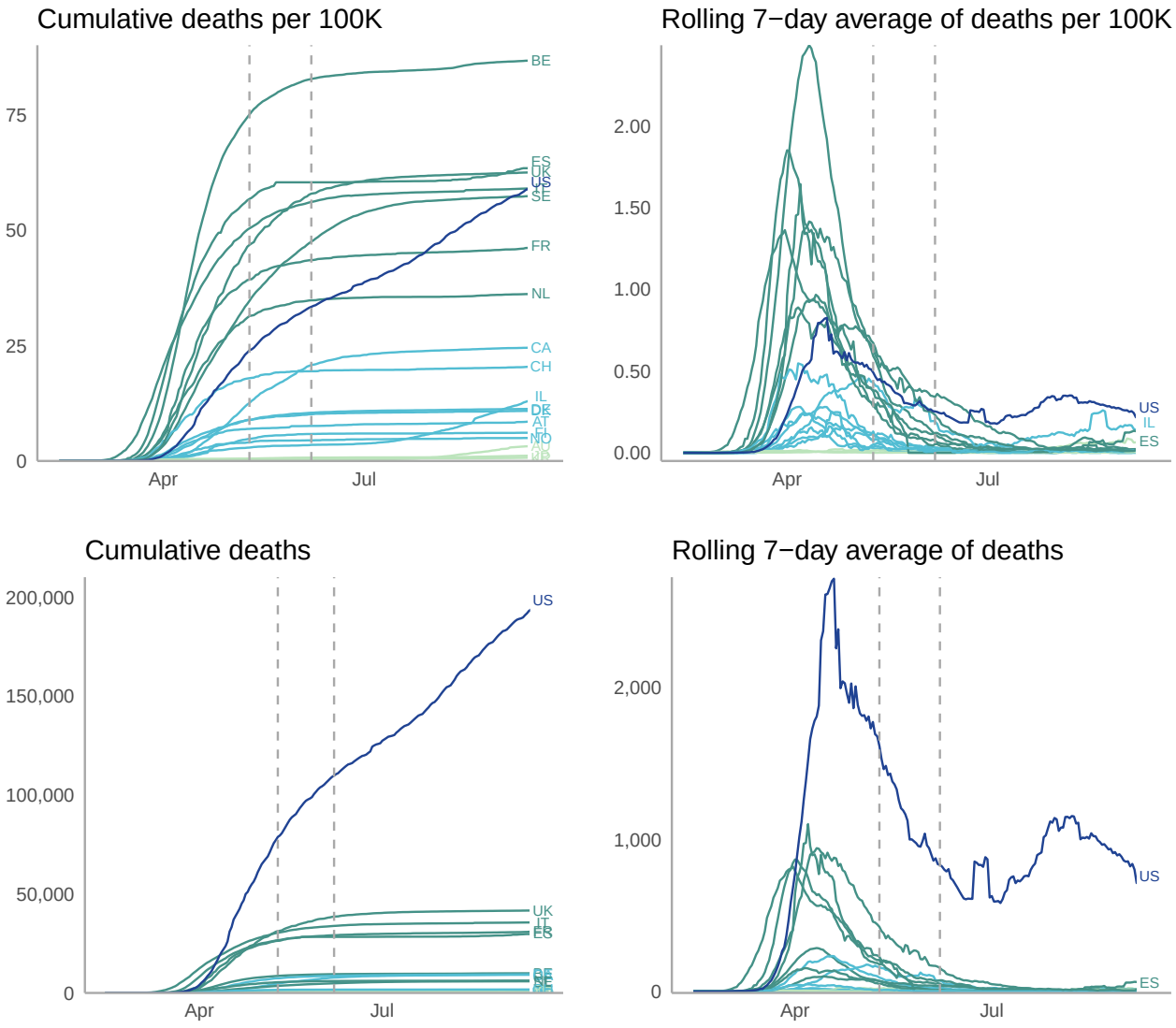

Figure 4 – Estimates of per capita and total COVID-19 mortality from February-September 2020.

Table S1 – Data on coronavirus disease 2019 (COVID-19) deaths are from February 13, 2020, through September 19, 2020 (n = 198 589 US deaths). Death rates per 100K Scenarios: (A) full sample; (B) since May 10, 2020; (C) since June 7, 2020; (D) since 60 days after surpassing 1 case per million; (E) since 60 days after surpassing 5 COVID-19 deaths. The last 5 columns assume that compared with the country in a given row, (A) the US had a comparable cumulative mortality rate; (B) the US mortality rate was unchanged until May 10 (n = 77 180 deaths), when it became comparable to the other country's death rate; and (C) the US mortality rate was unchanged until June 7 (n = 109 143 deaths), when it became comparable to the other country's death rate; (D) the US mortality rate was unchanged until 60 days after it reached 1 case per million (n = 68 934 deaths) when it became comparable to the other country's corresponding mortality rate; (E) the US mortality rate was unchanged until 60 days after it reached 5 deaths when it became comparable to the other country's corresponding mortality rate (n = 63 006 deaths).

Country	Date cases surpassed 1 per million	Deaths per 100K					Excess COVID-19 deaths vs. US (% of reported deaths)				
		(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
South Korea	2020-02-20	0.7	0.2	0.2	0.3	0	196,161 (99)	120,625 (61)	88,771 (45)	128,730 (65)	134,697 (68)
Japan	2020-02-23	1.2	0.7	0.5	1.0	1	194,711 (98)	119,090 (60)	87,939 (44)	126,260 (64)	132,782 (67)
Australia	2020-03-01	3.3	2.9	2.9	3.0	3	187,661 (94)	111,747 (56)	79,849 (40)	119,876 (60)	125,934 (63)
Norway	2020-02-29	5.0	1.0	0.5	1.4	1	182,099 (92)	118,074 (59)	87,655 (44)	125,085 (63)	133,421 (67)
Finland	2020-03-02	6.1	1.4	0.3	2.4	1	178,373 (90)	116,698 (59)	88,432 (45)	121,723 (61)	133,734 (67)
Austria	2020-03-01	8.6	1.7	1.0	2.2	2	170,247 (86)	115,874 (58)	86,066 (43)	122,449 (62)	130,605 (66)
Denmark	2020-03-04	10.9	2.1	0.8	3.0	2	162,600 (82)	114,438 (58)	86,669 (44)	119,850 (60)	130,596 (66)
Germany	2020-03-01	11.3	2.4	0.9	3.9	2	161,393 (81)	113,422 (57)	86,521 (44)	116,698 (59)	128,646 (65)
Israel	2020-03-02	14.0	11.2	10.6	11.5	11	152,393 (77)	84,676 (43)	54,529 (27)	91,763 (46)	100,202 (50)
Switzerland	2020-02-29	20.6	2.8	1.2	4.8	3	130,654 (66)	112,205 (57)	85,402 (43)	113,788 (57)	127,033 (64)
Canada	2020-03-06	24.6	12.4	4.0	14.8	10	117,622 (59)	80,631 (41)	76,235 (38)	81,075 (41)	103,539 (52)
Netherlands	2020-03-03	36.2	5.2	1.5	8.5	4	79,318 (40)	104,177 (52)	84,514 (43)	101,684 (51)	121,226 (61)
France	2020-03-01	46.6	7.5	3.2	11.3	10	45,142 (23)	96,763 (49)	78,947 (40)	92,389 (47)	104,382 (53)
Sweden	2020-02-29	57.4	23.5	10.3	31.7	23	9,581 (5)	44,210 (22)	55,607 (28)	25,469 (13)	60,604 (31)
Italy	2020-02-23	59.1	9.1	3.1	18.3	17	4,136 (2)	91,604 (46)	79,120 (40)	69,577 (35)	80,417 (40)
United Kingdom	2020-03-03	62.6	16.3	5.0	22.6	16	-7,459 (-4)	67,927 (34)	73,103 (37)	55,352 (28)	82,101 (41)
Spain	2020-02-29	65.0	8.6	4.6	14.2	9	-15,204 (-8)	93,247 (47)	74,163 (37)	82,872 (42)	105,829 (53)
Belgium	2020-03-01	86.8	12.4	4.2	19.9	11	-87,057 (-44)	80,475 (41)	75,572 (38)	64,218 (32)	100,624 (51)
United States of America	2020-03-07	60.3	36.9	27.2	39.4	41	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table S2 – Data on deaths are through July 25, 2020 (week 30, n = 235 610 excess US deaths compared with 145 546 reported COVID-19 deaths). Countries lacking publicly available all-cause mortality data through this time are omitted. Excess deaths were estimated by week, compared with 2015-2019 (except Germany: 2016-2019), beginning when a country surpassed 1 COVID-19 case per million population. Death rates per 100K Scenarios: (A) full sample; (B) since May 10, 2020; (C) since June 7, 2020; (D) since 60 days after surpassing 1 case per million; (E) since 60 days after surpassing 5 COVID-19 deaths. The last 5 columns assume that compared with the country in a given row, (A) the US had a comparable cumulative mortality rate; (B) the US mortality rate was unchanged until May 10 (n = 133 012 deaths), when it became comparable to the other country's death rate; and (C) the US mortality rate was unchanged until June 7 (n = 171 659 deaths), when it became comparable to the other country's death rate; (D) the US mortality rate was unchanged until 60 days after it reached 1 case per million (n = 118 366 deaths) when it became comparable to the other country's corresponding mortality rate; (E) the US mortality rate was unchanged until 60 days after it reached 5 deaths when it became comparable to the other country's corresponding mortality rate (n = 102 114 deaths).

	Deaths per 100K					Excess all-cause mortality vs. US (% of reported deaths)				
Country	(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
Norway	-2.6	-4.3	-2.1	-4.1	-3.6	235,610 (100)	102,598 (44)	63,952 (27)	117,245 (50)	133,496 (57)
Denmark	5.1	1.9	1.8	2.2	2.3	218,664 (93)	96,375 (41)	57,910 (25)	110,047 (47)	126,049 (53)
Israel	8.0	7.5	5.4	10.8	5.9	209,376 (89)	77,932 (33)	46,091 (20)	81,601 (35)	113,936 (48)
Germany	10.0	1.4	-0.2	2.9	1.4	202,547 (86)	97,905 (42)	63,952 (27)	107,803 (46)	128,803 (55)
Canada	13.3	-3.7	-7.6	-1.5	-5.3	192,009 (81)	102,598 (44)	63,952 (27)	117,245 (50)	133,496 (57)
Switzerland	17.0	-3.6	-2.7	-3.5	-3.6	179,545 (76)	102,598 (44)	63,952 (27)	117,245 (50)	133,496 (57)
Austria	17.1	3.2	1.4	4.3	2.9	179,208 (76)	92,042 (39)	59,375 (25)	103,159 (44)	123,905 (53)
Finland	19.1	8.7	5.4	11.8	6.3	172,706 (73)	74,116 (31)	46,264 (20)	78,517 (33)	112,624 (48)
Sweden	50.8	14.9	3.7	26.1	14.9	68,540 (29)	53,429 (23)	51,864 (22)	31,419 (13)	84,327 (36)
France	51.5	5.9	2.6	8.2	6.9	66,167 (28)	83,301 (35)	55,512 (24)	90,374 (38)	110,919 (47)
Netherlands	55.1	0.1	-0.7	5.1	0.1	54,282 (23)	102,157 (43)	63,952 (27)	100,603 (43)	133,054 (56)
Belgium	67.8	-4.6	-6.4	2.4	-4.6	12,638 (5)	102,598 (44)	63,952 (27)	109,253 (46)	133,496 (57)
United Kingdom	94.5	13.7	-1.2	32.1	13.7	-75,196 (-32)	57,659 (24)	63,952 (27)	11,769 (5)	88,557 (38)
Spain	102.2	2.1	1.8	7.1	4.3	-100,768 (-43)	95,784 (41)	57,948 (25)	93,952 (40)	119,420 (51)
United States of America	71.6	31.2	19.4	35.6	40.6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table S3 – This repeats Table S2 using 2017-19 as comparison years. Data on deaths are through July 25, 2020 (week 30, n = 212 702 excess US deaths compared with 145 546 reported COVID-19 deaths). Excess deaths were estimated by week beginning when a country surpassed 1 COVID-19 case per million population. Death rates per 100K Scenarios: (A) full sample; (B) since May 10, 2020; (C) since June 7, 2020; (D) since 60 days after surpassing 1 case per million; (E) since 60 days after surpassing 5 COVID-19 deaths. The last 5 columns assume that compared with the country in a given row, (A) the US had a comparable cumulative mortality rate; (B) the US mortality rate was unchanged until May 10 (n = 122 626 deaths), when it became comparable to the other country's death rate; and (C) the US mortality rate was unchanged until June 7 (n = 156 807 deaths), when it became comparable to the other country's death rate; (D) the US mortality rate was unchanged until 60 days after it reached 1 case per million (n = 108 932 deaths) when it became comparable to the other country's corresponding mortality rate; (E) the US mortality rate was unchanged until 60 days after it reached 5 deaths when it became comparable to the other country's corresponding mortality rate (n = 93 905 deaths).

	Deaths per 100K					Excess all-cause mortality vs. US (% of reported deaths)				
Country	(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
Norway	-6.4	-5.4	-2.9	-5.9	-4.6	212,702 (100)	90,076 (42)	55,896 (26)	103,770 (49)	118,797 (56)
Germany	-3.4	-2.0	-2.6	-0.3	-2.0	212,702 (100)	90,076 (42)	55,896 (26)	103,770 (49)	118,797 (56)
Denmark	-3.3	-1.4	-0.8	-1.3	-0.9	212,702 (100)	90,076 (42)	55,896 (26)	103,770 (49)	118,797 (56)
Canada	3.2	-9.3	-11.0	-7.6	-10.3	202,169 (95)	90,076 (42)	55,896 (26)	103,770 (49)	118,797 (56)
Austria	10.0	0.5	0.0	2.1	0.1	179,940 (85)	88,275 (42)	55,896 (26)	96,880 (46)	118,444 (56)
Israel	10.3	8.1	6.0	11.8	6.3	178,963 (84)	63,367 (30)	36,158 (17)	64,913 (31)	98,229 (46)
Switzerland	10.3	-5.6	-3.4	-6.2	-5.6	178,869 (84)	90,076 (42)	55,896 (26)	103,770 (49)	118,797 (56)
Finland	11.4	7.2	3.5	10.3	4.4	175,042 (82)	66,222 (31)	44,267 (21)	69,868 (33)	104,246 (49)
France	35.7	-1.1	-2.0	0.3	-0.6	95,170 (45)	90,076 (42)	55,896 (26)	102,739 (48)	118,797 (56)
Netherlands	47.0	-2.6	-2.7	2.7	-2.6	58,177 (27)	90,076 (42)	55,896 (26)	94,736 (45)	118,797 (56)
Sweden	52.7	17.3	4.3	28.9	17.3	39,134 (18)	32,998 (16)	41,887 (20)	8,607 (4)	61,718 (29)
Belgium	61.6	-5.5	-7.4	2.5	-5.5	9,843 (5)	90,076 (42)	55,896 (26)	95,526 (45)	118,797 (56)
United Kingdom	91.9	13.6	-1.2	32.0	13.6	-89,806 (-42)	45,373 (21)	55,896 (26)	-1,535 (-1)	74,094 (35)
Spain	99.7	2.0	2.2	6.7	4.0	-115,342 (-54)	83,532 (39)	48,622 (23)	81,704 (38)	105,722 (50)
United States of America	64.6	27.4	17.0	31.5	36.1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

REGRESSIONS

Table 1

Let d_i be the number of deaths in country i over some time period, and p_i be its population. Assume we have countries $j = 1, ..., n$ and $\mathbf{C}$ be a $(n-1) \times 1$ vector of country indicator variables with the US omitted as reference category. We assume that $d_i \sim Pois(\lambda_i)$ and

$$\mathbb{E}\left[log(\lambda_i)\right] = \beta_0 + \boldsymbol{\beta}\mathbf{C} + log(p_i), \tag{4}$$

where $\boldsymbol{\beta}$ is $1 \times n-1$ and β_j compares the death rate in country j to the US.

Table 2

Let $d_{i,w,y}$ be the number of deaths in country i at week w in year y, and p_i be its population. Assume we have countries $j = 1, ..., n$ and $\mathbf{C}$ be an $(n-1) \times 1$ vector of country indicator variables with the US omitted as reference category, $\mathbf{W}$ be a $(W-1) \times 1$ vector of week indicator variables, and $\mathbb{I}_{2020}$ be equal to 1 if the year is 2020 and 0 otherwise. We assume that $d_{i,w,y} \sim Pois(\lambda_{i,w,y})$ and

$$\mathbb{E}\left[log(\lambda_{i,w,y})\right] = \beta_0 + \boldsymbol{\beta}\mathbf{C} + \boldsymbol{\gamma}\mathbf{W} + \delta\mathbb{I}_{2020} + \boldsymbol{\alpha}\mathbf{C}\mathbb{I}_{2020} + log(p_i), \tag{5}$$

where $\boldsymbol{\alpha}$ is $1 \times n-1$ and α_j compares excess 2020 mortality in country j to in the US.[3]

DATA SOURCES

We accessed data on **COVID-19 deaths** from the **European Centre for Disease Prevention and Control COVID-19 database** (link, accessed through R library sars2pack). We accessed **all-cause mortality data** from country-specific sources (Table S4). We also referenced *The Economist* (link) and *The New York Times* (link) excess death GitHubs and associated coverage.

[3]For estimation strategies, see Weinberger DM, Chen J, Cohen T, et al. Estimation of Excess Deaths Associated With the COVID-19 Pandemic in the United States, March to May 2020. JAMA Intern Med. Published online July 1, 2020. doi:10.1001/jamainternmed.2020.3391.

Country	Source	File	Included	Week format	Notes	Link
Australia	Australian Bureau of Statistics	Provisional Mortality Statistics	No		Data only available through May 2020	link
Austria	Statistics Austria	Age-specific death rates in Austria (excl. deaths abroad) by calendar week	Yes	Sunday-Saturday		link
Belgium	Statbel	Number of deaths per day, sex, age, region, province, district	Yes	Daily data, aggregated by week (Monday-Sunday)		link
Canada	StatCan	Adjusted number of deaths, expected number of deaths and estimates of excess mortality, by week	Yes	Monday-Sunday		link
Denmark	Statistics Denmark	DODC1: Deaths per day (experimental statistics) by sex and age	Yes	Daily data, aggregated by week (Monday-Sunday)		link
Finland	Statistics Finland	12ng – Deaths by week according to sex, age and region (Rapid estimate), 1990W01-2020W37*	Yes	Sunday-Saturday		link
France	Insée	Téléchargement des fichiers des décès quotidiens	Yes	Daily data, aggregated by week (Monday-Sunday)	Economist GitHub approach for all-cause mortality 2015-17	link, link, link
Germany	DeStatis	Sterbefälle - Fallzahlen nach Tagen, Wochen, Monaten, Altersgruppen und Bundesländern für Deutschland 2016 - 2020	Yes	Daily data, aggregated by week (Monday-Sunday)	Only available starting in 2016	link
Israel	Ministry of Health	Weekly Epidemiological Reports	Yes	Reports dated Saturday	Received translation assistance	link
Italy	Istat	10 August 2020 – Male, female and total deaths	No		Data only available through June 2020	link
Japan	e-Stat	Current Population Survey / Vital Statistics	No		Data only available through July 2, 2020	link
Netherlands	StatLine	Deaths registered weekly, by sex and age	Yes	Sunday-Saturday		link
Norway	Statistics Norway	07995: Deaths, by sex, age and week. Preliminary figures 2000 - 2020	Yes	Sunday-Saturday		link
South Korea	Statistics Korea	Vital statistics (births/deaths)	No		Received translation assistance; data only available monthly	link
Spain	Instituto Nacional de Estadística	Estimate of Weekly Deaths	Yes	Sunday-Saturday		link
Sweden	Statistics Sweden	Preliminary statistics on deaths in Sweden		Daily data, aggregated by week (Monday-Sunday)		link
Switzerland	Federal Statistics Office	Weekly number of deaths, 2020 & 2010-2019		Sunday-Saturday		link
United Kingdom	Office of National Statistics (GB), National Records of Scotland, Northern Ireland Statistics and Research Agency	Deaths registered weekly in England and Wales, provisional, Deaths involving coronavirus (COVID-19) in Scotland, Weekly death registrations in Northern Ireland, 2020.	Yes	Sunday-Saturday, Monday-Sunday		link, link, link
United States	Centers for Disease Control and Prevention	Deaths involving coronavirus disease 2019 (COVID-19), pneumonia, and influenza reported to NCHS by week ending date, United States. Week ending 2/1/2020 to 9/19/2020.	No	Monday-Sunday		link

Table S4 – Data sources for all-cause mortality. The "Included" column indicates whether available data met inclusion criteria; if not, this is explained in the "Notes" column. Due to differences in reporting, week definition varies slightly.