

Supplementary Material

Table S1. Summary of data relating to each country included in the influenza vaccine doses distributed analysis. The column “10% achieved” gives the winter at which 10% population vaccination coverage was achieved.

Country	Latitude	EWM adjustment	Data (n) up to 2013/14	Vaccination	
				Range	10% achieved
Singapore	1.3	1.650	34	0%-10%	2009/10
Hong Kong	22.3	0.656	33	1%-15%	2003/04
South Korea	36.1	1.463	23	5%-41%	1996/97
Japan	36.3	0.668	33	0%-51%	2000/01
USA(!)	38.0	1.000	40	6%-53%	1988/89
Turkey	39.1	0.981	4	3%-4%	No
Portugal	39.6	0.443	34	1%-25%	1994/95
Greece	39.7	1.150	14	12%-32%	2000/01
Armenia	40.3	0.471	22	0%	No
Spain	40.4	0.590	34	5%-34%	1988/89
Macedonia	41.4	0.826	21	0%-1%	No
Kyrgyzstan	41.5	1.600	8	0%	No
Uzbekistan	41.8	0.979	7	0%-1%	No
Italy	42.5	0.746	24	15%-34%	1984/85
Montenegro	42.8	0.993	9	0%-7%	No
Bosnia and Herzegovina	43.7	0.939	10	0%-4%	No
San Marino	43.9	0.453	26	0%-15%	2004/05
France	46.6	1.080	34	9%-36%	1988/89
Switzerland	46.8	0.900	34	5%-22%	1998/99
Austria	47.6	0.996	34	1%-17%	1999/00
Kazakhstan	48.1	1.520	21	2%-4%	No
Ukraine	48.4	1.060	30	0%-2%	No
Luxembourg	49.6	0.924	12	15%-48%	2004/05
Belgium	50.6	0.854	34	5%-27%	1993/94
Germany	51.9	1.200	34	6%-35%	1997/98
Poland	52.1	1.040	34	1%-10%	2001/02
Netherlands(α)	52.3	1.070	44	3%-46%	1994/95
Ireland	53.2	0.738	22	3%-31%	2002/03
UK	54.6	0.760	26	2%-33%	1995/96
Canada	56.1	1.090	34	4%-38%	1990/91
Denmark	56.1	1.100	32	0%-26%	1998/99
Latvia	56.9	1.095	25	1%-14%	2005/06
Estonia	59.4	1.120	34	1%-7%	No
Sweden	62.7	0.990	34	0%-21%	2001/02
Finland(α)	64.3	1.240	44	2%-34%	1995/96
Iceland	64.9	0.935	34	1%-28%	1986/87
Norway	66.8	1.020	34	1%-16%	1995/96

(!) Data for USA extended to 2019/20 due to doses data available from US CDC. (α) Low vaccination at the beginning of the time series enables extrapolation back in time using an assumed linear trend.

Table S2. Summary of data relating to each country (n=98) included in the proportion elderly vaccinated study.

Country	EWM Adjustmen t	Media n EWM	Data (n=)	Age 65+ vaccinated (%)		
				Minimu m	Maximu m	Median
Albania	0.44	31.2%	13	0%	14%	6%
Armenia	0.47	24.6%	15	0%	2%	0%
Australia	0.72	16.6%	32	12%	79%	58%
Austria	0.87	13.8%	33	0%	49%	21%
Azerbaijan	0.79	14.9%	21	0%	0%	0%
Bahamas	0.99	12.1%	22	0%	27%	0%
Barbados	0.87	13.8%	6	0%	40%	8%
Belarus	1.38	9.4%	18	5%	76%	23%
Belgium	0.72	15.4%	33	15%	65%	57%
Bermuda	0.62	19.6%	17	0%	12%	0%
Bosnia and Herzegovina	0.97	12.4%	10	0%	0%	0%
Bulgaria	0.71	17.6%	20	2%	20%	8%
Canada	1.03	11.6%	33	25%	71%	60%
Chile	0.57	21.2%	32	3%	68%	18%
Costa Rica	1.54	8.2%	26	0%	50%	15%
Croatia	0.78	16.0%	31	0%	43%	23%
Cuba	1.22	9.7%	26	0%	99%	28%
Cyprus	0.52	22.0%	18	23%	49%	33%
Czechia	1.08	11.4%	28	0%	24%	17%
Denmark	1.08	11.1%	33	4%	52%	20%
Egypt	0.90	13.4%	25	0%	1%	0%
El Salvador	1.20	10.0%	23	0%	42%	12%
England	0.68	17.6%	33	12%	75%	71%
Estonia	1.10	10.9%	32	0%	20%	2%
Finland	1.12	10.7%	33	4%	52%	40%
France	0.87	13.7%	33	39%	67%	52%
Georgia	0.63	18.9%	16	0%	0%	0%
Germany	1.00	12.0%	33	13%	63%	38%
Greece	1.04	11.0%	20	20%	59%	49%
Greenland	0.66	18.1%	28	0%	0%	0%
Guadeloupe	1.18	10.1%	6	0%	18%	9%
Guam	0.79	15.3%	11	0%	0%	0%
Guatemala	2.42	5.0%	9	1%	15%	9%
Hong Kong SAR	0.67	20.2%	33	0%	44%	5%
Hungary	1.03	11.7%	32	13%	39%	27%
Iceland	1.01	11.5%	31	35%	49%	43%
Ireland	0.75	15.8%	20	38%	70%	59%

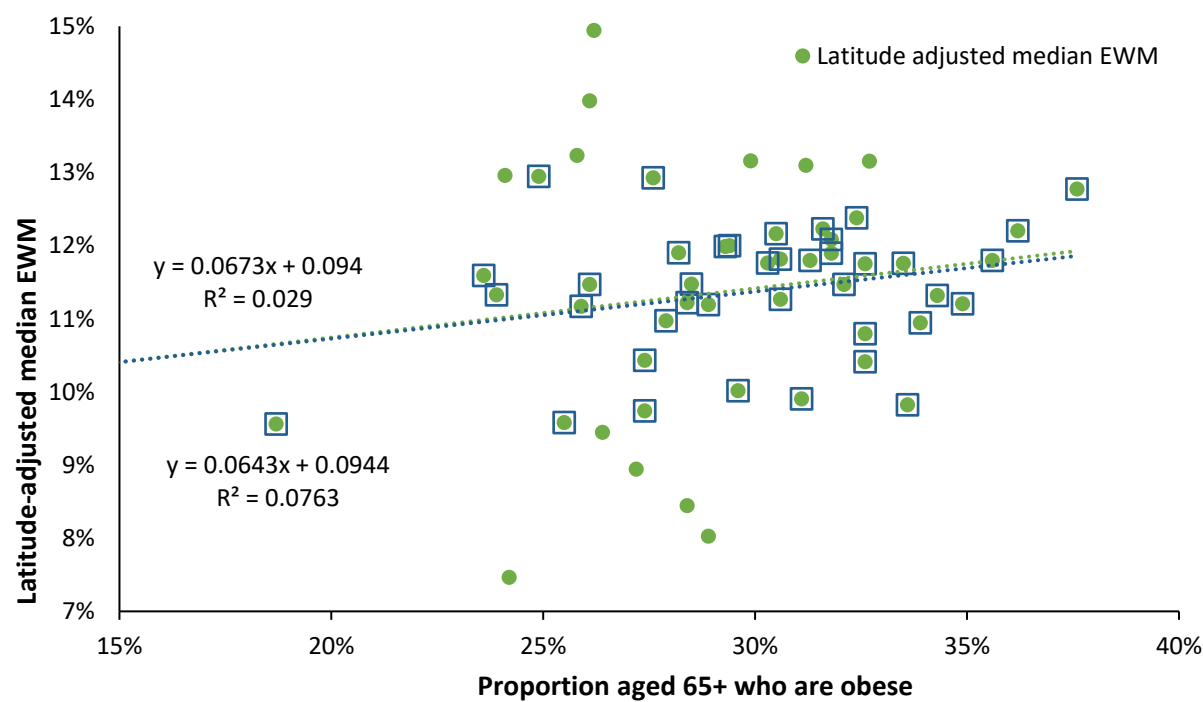
Country	EWM Adjustment	Median EWM	Data (n=)	Age 65+ vaccinated (%)		
				Minimum	Maximum	Median
Israel	0.57	21.4%	27	43%	66%	49%
Italy	0.75	16.0%	29	40%	68%	52%
Japan	0.64	18.9%	33	0%	57%	48%
Kazakhstan	1.54	7.6%	18	1%	15%	3%
Kosovo	0.80	15.0%	9	0%	0%	0%
Kuwait	0.75	17.0%	28	0%	23%	4%
Kyrgyzstan	1.76	6.8%	13	0%	7%	1%
Latvia	1.01	12.1%	31	0%	15%	3%
Lebanon	0.63	18.9%	20	5%	35%	15%
Liechtenstein	0.47	25.6%	32	20%	30%	27%
Lithuania	0.95	12.7%	26	0%	25%	9%
Luxembourg	0.93	13.0%	30	15%	54%	40%
Macao SAR	0.57	21.0%	31	9%	36%	25%
Malaysia	2.13	5.6%	24	0%	1%	0%
Maldives	0.89	13.6%	24	0%	6%	0%
Malta	0.37	34.0%	30	20%	57%	46%
Martinique	1.43	9.0%	11	0%	6%	0%
Mauritius	0.86	13.9%	26	0%	51%	14%
Mexico	0.74	15.9%	27	1%	88%	51%
Mongolia	1.16	10.4%	15	0%	15%	0%
Montenegro	0.89	13.5%	14	14%	31%	17%
Netherlands	0.89	13.4%	32	25%	84%	70%
New Caledonia	0.83	14.6%	23	7%	35%	21%
New Zealand	0.67	18.4%	33	9%	69%	58%
North Macedonia	0.83	14.7%	22	0%	12%	4%
Northern Ireland	0.71	17.0%	31	12%	78%	72%
Norway	0.96	12.4%	33	15%	44%	31%
Philippines	1.77	6.8%	16	0%	9%	2%
Poland	1.09	11.7%	33	0%	32%	8%
Portugal	0.44	27.4%	33	0%	65%	42%
Puerto Rico	1.18	10.2%	22	0%	37%	8%
Qatar	0.88	13.2%	23	0%	59%	5%
Republic of Moldova	0.66	18.3%	20	0%	5%	3%
Reunion	1.03	12.5%	10	0%	0%	0%
Romania	0.71	17.3%	32	0%	29%	15%
Russian Federation	1.79	6.7%	23	1%	69%	14%
Saint Lucia	0.78	15.3%	4	0%	0%	0%
Saint Vincent & Grenadines	0.73	16.1%	17	0%	20%	0%
Scotland	0.81	14.8%	30	12%	77%	72%
Serbia	0.95	12.7%	19	0%	15%	9%

Country	EWM Adjustment	Median EWM	Data (n=)	Age 65+ vaccinated (%)		
				Minimum	Maximum	Median
Singapore	1.56	7.4%	31	2%	21%	8%
Slovakia	1.32	9.1%	29	0%	38%	14%
Slovenia	0.83	14.2%	32	0%	35%	13%
South Africa	0.95	12.6%	18	0%	17%	3%
South Korea	1.46	8.2%	27	9%	86%	73%
Spain	0.60	20.0%	33	37%	70%	58%
Sri Lanka	1.12	10.7%	13	0%	0%	0%
Suriname	1.31	9.1%	16	0%	0%	0%
Sweden	0.94	12.7%	33	13%	66%	44%
Switzerland	0.82	14.6%	32	14%	61%	36%
Trinidad and Tobago	1.44	9.6%	17	0%	25%	2%
Turkey	0.82	14.6%	21	1%	13%	6%
Ukraine	1.10	11.5%	27	0%	70%	0%
United Kingdom	1.00	12.0%	33	12%	75%	71%
Uruguay	0.42	30.5%	18	0%	70%	0%
US Virgin Islands	0.86	15.0%	7	0%	16%	2%
USA	1.00	12.0%	33	36%	71%	65%
Uzbekistan	1.30	9.2%	12	0%	13%	0%
Venezuela	1.59	8.0%	13	0%	50%	15%
Wales	0.74	16.1%	20	9%	69%	60%

Table S3. Example of high/Low behaviour in EWM for american states over the 13 winter seasons ending 2019/20. Winter of 2019/20 was truncated at March to avoid the effects of COVID-19. High/low groups are by visual inspection due to the gap between the range for high and low values.

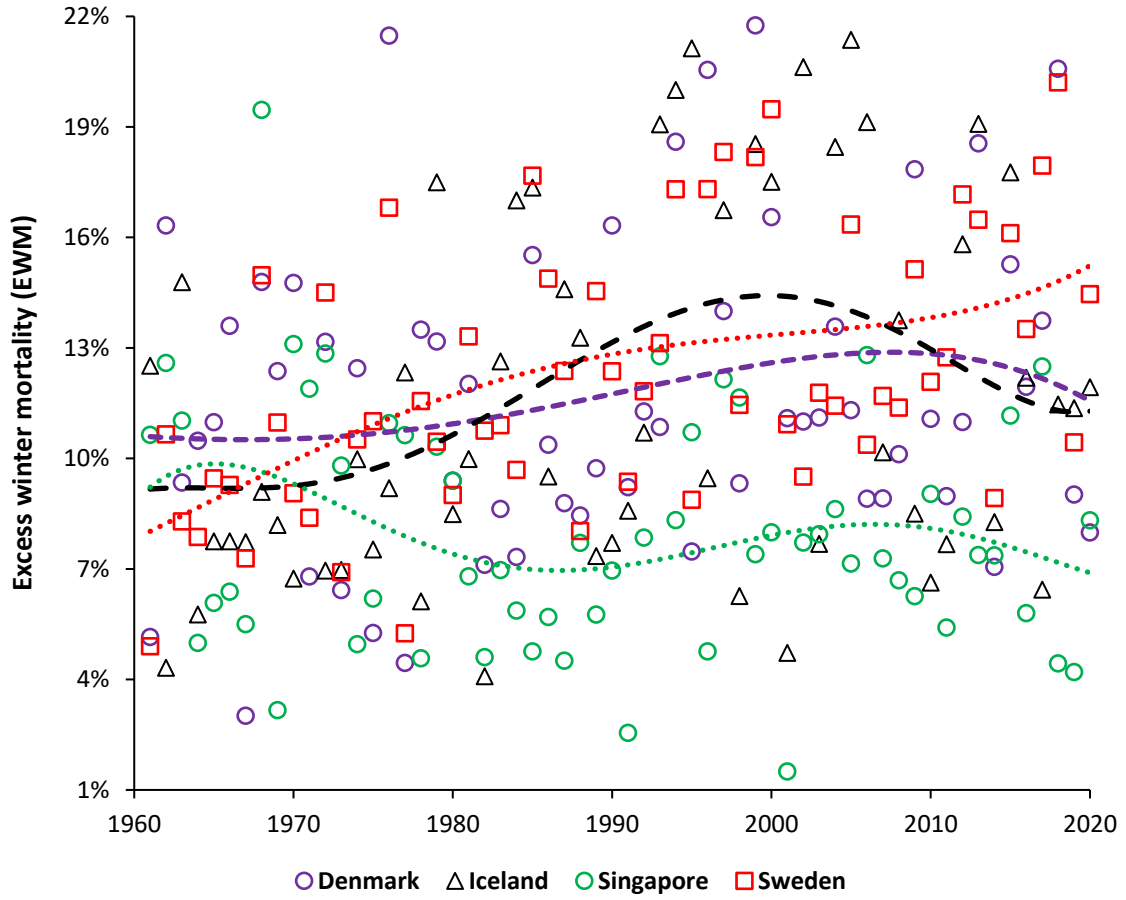
State	High/Low	EWM Range	Frequency
USA	High	14%-16%	6
	Low	7%-10%	7
Arizona	High	11%-16%	8
	Low	6%-10%	5
Alaska	High	9%-15%	7
	Low	5%-6%	6
New Jersey	High	14%-16%	7
	Low	8%-10%	6
New York	High	14%-16%	6
	Low	6%-10%	7
Ohio	High	14%-18%	5
	Low	8%-10%	8
Texas	High	14%-16%	5
	Low	9%-11%	8
Wyoming	High	9%-14%	7
	Low	4%-8%	6
Wisconsin	High	10%-16%	8
	Low	6%-9%	5
West Virginia	High	10%-16%	10
	Low	6%-8%	3

Figure S1. Relationship between median EWM among American states and proportion of persons aged 65+ who are obese



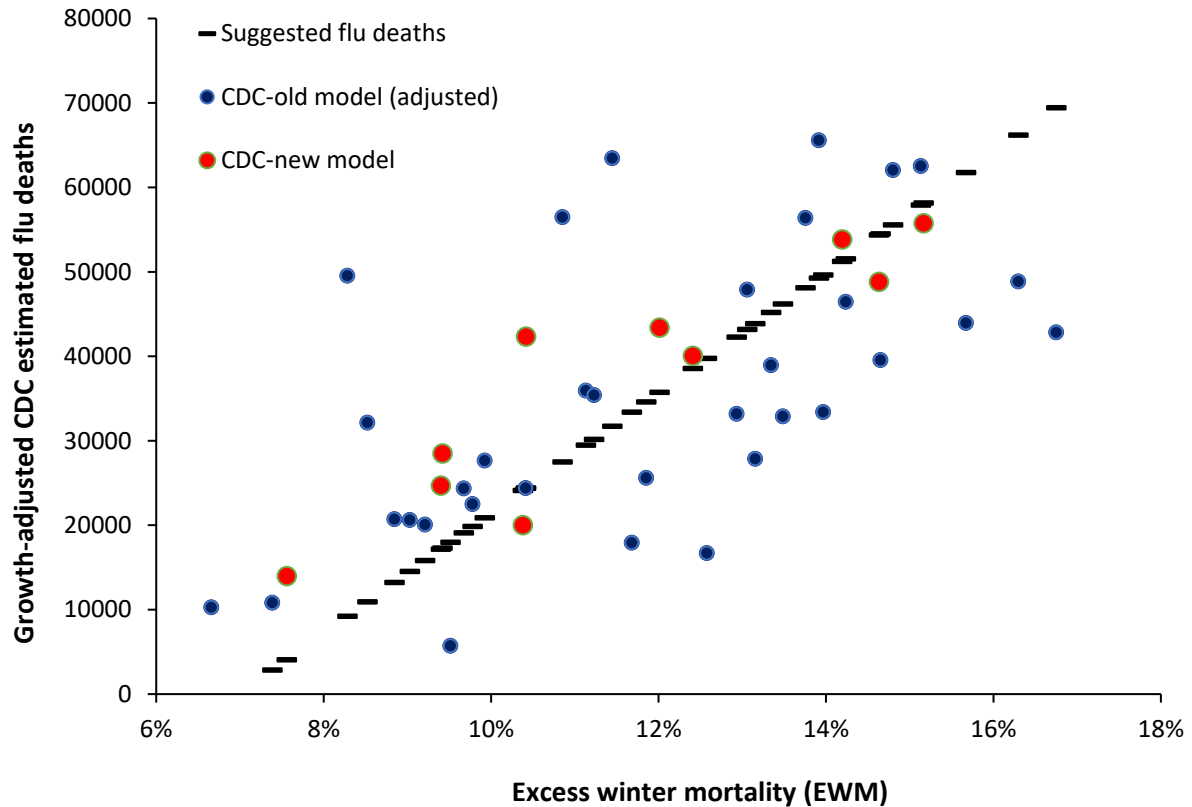
Footnote: Data regarding obesity in those aged 65+ in 2020 was from DNPAO Data, Trends and Maps: Explore by Topic | CDC. The slope has been calculated using all states or after trimming high/low EWM states. As can be seen trimming has negligible effect on the observed slope.

Figure S2. Trend in EWM for Denmark, Iceland, Singapore, and Sweden over the 60-year period 1960 to 2020



Footnote: The trend for each country is estimated using a 4th or 5th order polynomial. Singapore (closest to the equator) seems to have a slight downward trend while Sweden appears to have the highest trend upward. During the period 1992 to 2010 obesity among Singaporeans aged 60 – 69 was static [60]. Singapore has traditionally been a low influenza vaccination country. The trends are dominated by very high year-to-year volatility which is reflected in the high volatility in Figure 6. Since this study ran from 1980 onward it is considered that adjustment for the underlying trends relative to the USA would make only a small impact on the observed volatility in Figure 6. The non-linear trends are consistent with the overall observation of this paper that long-term trends in EWM are regulated by complex factors.

Figure S3. US CDC estimated flu deaths (adjusted for growth in deaths over time) versus EWM.



Footnote: CDC estimated flu deaths were first adjusted for the growth in total deaths over time. Data is from [75-77]. The underlying trend in total deaths was determined from a series of polynomial curve fits giving an adjustment factor for each year taking flu deaths to the 2020 equivalent. Over time the CDC has used two models to estimate flu deaths (old model covers 1976/77 to 2006/07, while the new model is from 2007/08 onward) of which the most recent model gives higher estimated flu deaths [75-77]. Data from the earlier model was adjusted up to the more recent model by plotting both sets of data against EWM and using the difference between the regression lines as the adjustment factor. The line for suggested flu deaths is in line with Figures 5 and A3 and assumes that zero flu deaths occur at an EWM around 7% to 8%. Note the far higher scatter in the old CDC results. The R-squared for the old model is 0.448 while that for the new model is 0.8403. This scatter arises because the CDC uses a limited sample of hospitals from which admissions and other data are used to estimate flu deaths. As a result, there are multiple sampling issues, hidden assumptions, and adjustment factor issues. While the new CDC model has a higher R-squared, the CDC models are less reliable than may be expected and lead to over-estimated influenza deaths.

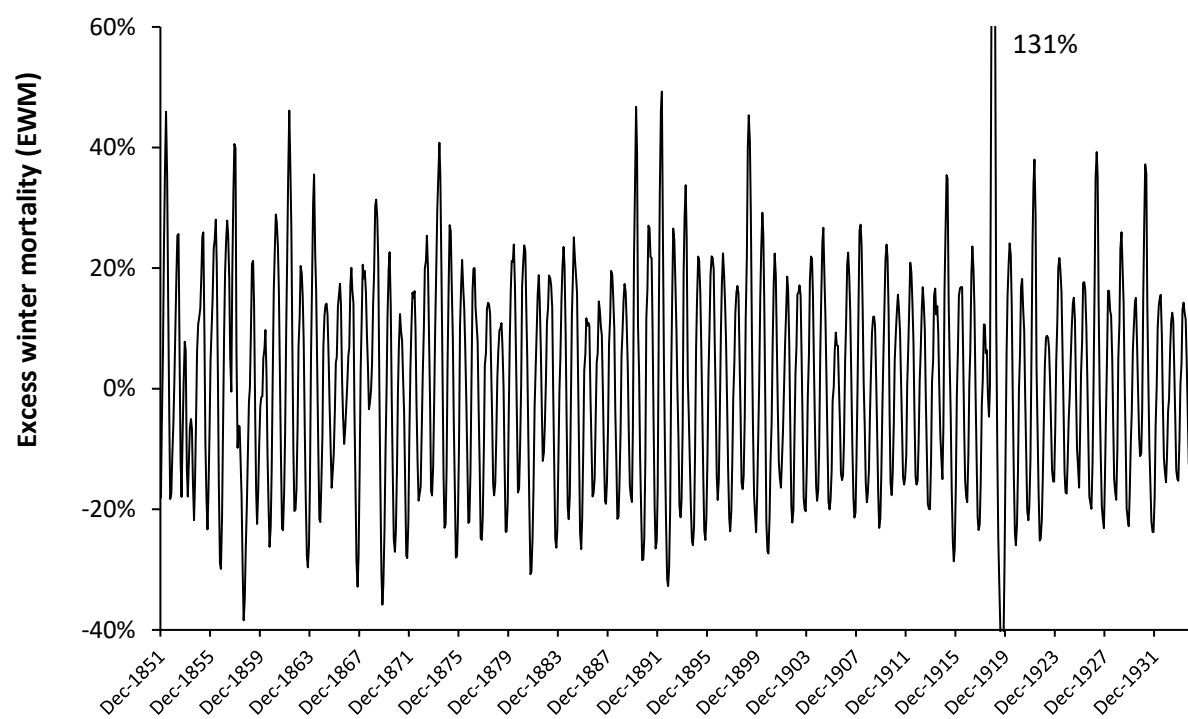
On average the new CDC model possibly overestimates flu deaths by around 14%. For the old model the high years gives flu deaths which are incompatible with excess winter deaths (EWD).

After adjusting all years for the growth in total deaths in the USA over the period 1957/58 to 2019/20 there was a median of 1.047 million winter deaths (interquartile range 1.027 – 1.063 million), a median excess winter deaths of 108,500 (IQR 89,800 – 130,700), and a median estimated winter influenza deaths of 30,000 (IQR 20,000 – 43,000). Estimated influenza deaths as a proportion of excess winter deaths had a median of 28% (IQR 20% - 36%). The proportion influenza deaths reached a maximum

of 50% of excess winter deaths in the winter of 2001/02, which was not a pandemic year. Hence within these ranges there is ample opportunity for the estimated influenza deaths to “steal” from otherwise unrelated reported cause of death in persons who would otherwise have died in that year.

For the USA, EWM reached a minimum in 2011/12 of 7.6% and the US CDC noted that this winter set a record for the lowest and shortest peak in ILI [78]. Outpatient visits, inpatient admissions and deaths were at baseline levels, i.e., 2011/12 represents the lowest possible influenza year. Other than 3 high years between 1997/98 to 1999/00 (14.2%, 15.7%, 16.8% EWM), EWM reached a maximum of 15.2% during the winter of 2014/15 and 14.2% in 2017/18. Both of the later years saw high influenza outpatient visits, hospitalizations, and deaths [79,80]. Hence EWM is correctly detecting the severity of each influenza season. The CDC estimated 12,000 influenza deaths in 2011/12 and 52,000 in 2017/18 [75-77].

Figure S4. Rolling/moving EWM calculation for Sweden, 1851 to 1920



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