An international comparison of the second derivative of COVID-19 deaths after implementation of social distancing measures

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This work compares deaths for confirmed COVID-19 cases in China to six other countries, Italy, Spain, France, USA, UK and South Korea. Several appear to be converging onto the decline in the daily growth rate of deaths, or relative second derivative of total deaths, seen in China after that country implemented aggressive social distancing. By calculating future trajectories in these countries based on the observed Chinese fatality statistics, an estimate of the total deaths and maximum daily death rates is made.

These six countries are the focus of this analysis as they have sufficient total deaths, greater than about 100, to derive estimates of the second derivative. All of them also have initiated social distancing measures at different points in time. Iran has been excluded as the very low variance in the data is not compatible with the statistics seen in the other seven countries analysed.

Fig. 1 shows the relative second derivative, $1/N\ \mathrm{d}^2N/\mathrm{d}t^2$ in total deaths, N, plotted as a times series for each country compared to China, calculated after total deaths were greater than 20. An exponential rate corresponds to a constant value over time, but for China the daily rate has been falling from an initial 50% to very close to zero, with the fall occurring over a 30-day period after lockdown was announced for Wuhan on 23/01/2020. In fig. 1, the time series of the other countries have been aligned to best match the trajectory seen in China, with the announcement of lockdowns and implementation of social distancing measures marked. Comparing each country to China, the daily growth rate in total deaths in Italy has been closely following the trajectory for the last 11 days subsequent to the announcement of lockdown in Lombardy on 8/3/2020. Spain has also seen some convergence on China's trajectory for the last 6 days following a national lockdown implemented on 12/3/2020, but with a higher variance. In the case of France, although lock-down measures came into force on 16/3/2020, the trajectory has only converged for the last three days. Similar to France, the USA shows limited evidence yet of convergence, with lockdowns implemented only to the state level at the time of writing; we expect the estimated total deaths will continue to climb rapidly unless convergence is maintained beyond the two days seen to present. The UK has converged on China's trajectory for the last 5 days, with a higher variance which in part is due to the sampling statistics from a relatively low fatality count to date; although no lockdown has been announced, general social distancing was advised by the government on 16/3/2020. South Korea has seen a much lower rate of growth

from the start and announced a number of suppression policies, including monitoring, testing and restricting non-essential travel from 20/2/2020.

If these countries continue to converge onto the Chinese trajectory, the total and daily deaths can be estimated (fig. 2) by deriving a multiplier at the point of convergence to predict the number of deaths. Fig. 3 plots this multiplier with date of convergence. For example, on 4/3/2020 when South Korea converged onto the Chinese trajectory its total deaths were 32. The rate at that time corresponds to the rate seen in China on 8/2/2020, resulting in a corresponding multiplier of 4.5, and predicted total deaths of 144. Current cumulative deaths in South Korea are 103, consistent with South Korea continuing to follow China's trajectory, with an estimate, on 22/03/2020, of 130 total deaths, within 10% of the initial estimate. The conditions for a reduced death toll according to this calculation are a low number of deaths prior to convergence, and a point of convergence that is at an advanced point in the Chinese trajectory. South Korea fulfils both conditions. As this multiplier depends on the date of convergence, the sensitivity of this estimate can be calculated for an offset of ±1 day. On the basis of this assumption, the projected total deaths and a sensitivity range are shown in Table 1.

The observed convergences to date, at an early point in the Chinese trajectory, for Italy, Spain, France and the UK would indicate convergence of the combined transmission and fatality rate for these five countries. If a similar fatality rate is assumed, this would imply these countries are converging on the same trajectory in transmission rates, the stated goal of efforts at social distancing.

Although the strength of social distancing has varied in all four countries, with China's the most restrictive and closely monitored, overall these measures appear to be sufficient at this time to produce a similar fall in cumulative death rates. This implies there may be a threshold of intervention sufficient to achieve the desired trajectory. However, the divergence of France and the USA from this behaviour until now requires explanation. Both countries experienced initial lower rates of cumulative deaths and this possibly reduced the level of public compliance with policies of lock down and social distancing [3]. South Korea's policies, with intervention at an early stage, has been successful in reducing the rate of increase in deaths to that seen in the latter stages of lockdown in Wuhan.

These estimates are based on each of the six countries following China's trajectory from the present, but because of their deaths before convergence, all would still expect from two to eight times the number of total and daily deaths, with the exception of South Korea. Based on this model, it would be unexceptional to see daily deaths of 1000 in Italy in the near future even as it remains on the trajectory, despite following the downwards trajectory of growth in daily death rates seen in China. In general, this analysis suggests that early adoption of social distancing is more effective than delayed implementation, even of highly restrictive measures. If China's policies aimed at suppression represent a maximum possible reduction in transmission from initially high rates, then these estimates will undercount both the total deaths and maximum death rates for other countries and hence represent a reasonable lower bound for modelling: the lowest estimate of total deaths in the models in Ferguson et al. [3] is 5,600, very similar to the expected value of 5,800 we predict if the UK follows China's trajectory from 23/03/2020.

This simple method of viewing the data may be helpful in monitoring the course of the epidemic at national and regional levels, judging the effectiveness of implementation in individual countries, planning for and monitoring the relaxation of social distancing, and potentially improving time estimates for economic projections.

References

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[3] Ferguson et al., Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand https://www.imperial. ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19- NPI- modelling-16-03-2020.pdf

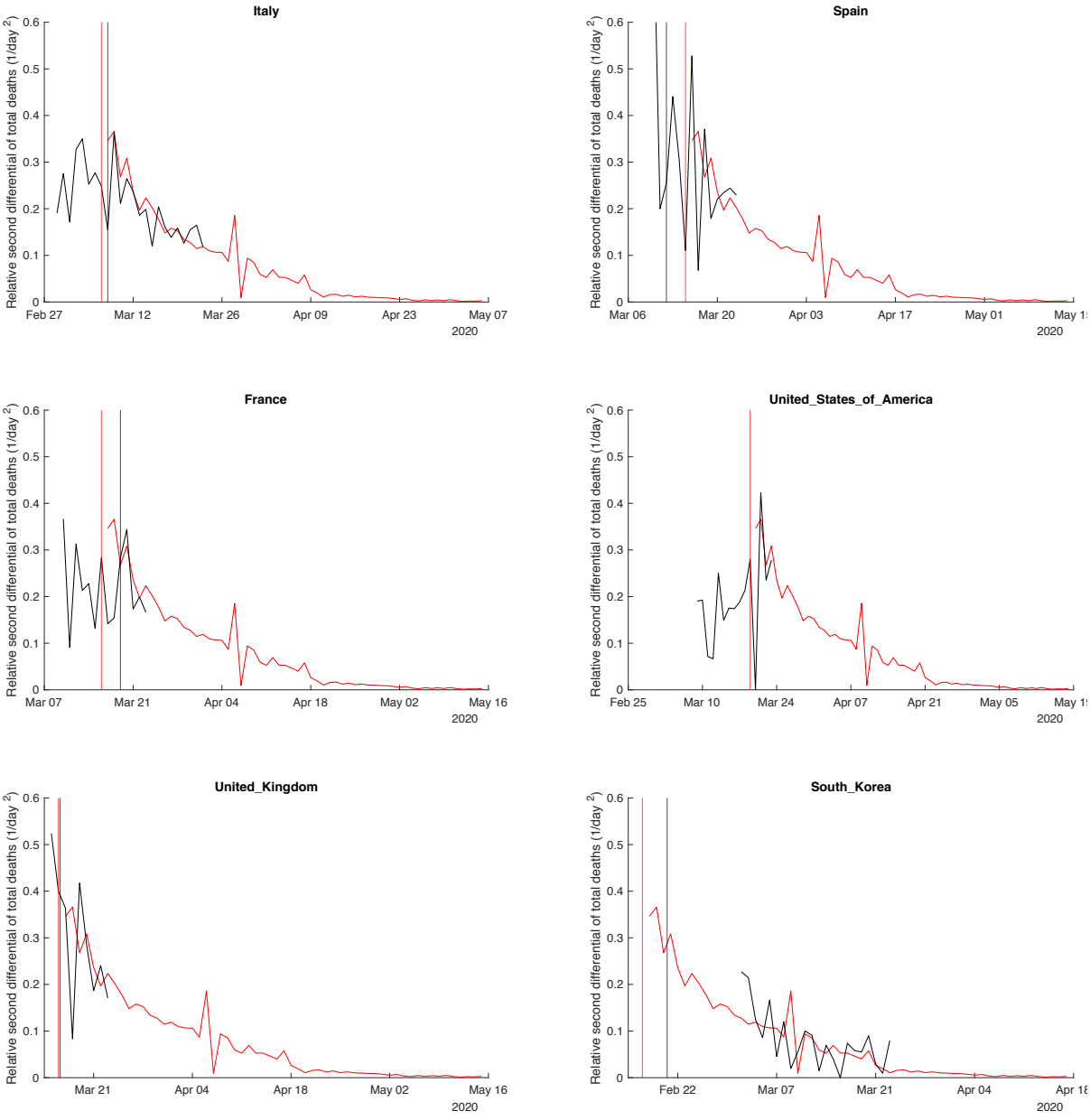

Figure 1: Relative second differential of total COVID-19-positive deaths in each country, plotted in black, up to 22/3/2020 compared to China, plotted in red. Dates correspond to the country compared to China. The time series have been shifted to best align with the trajectory seen in China after lockdown was announced in Wuhan on 23/01/2020, marked in red. The dates of lockdown in Lombardy, Spain and France, and social distancing in the UK are marked in black. Data source: European Centre for Disease control, ECDC [1].

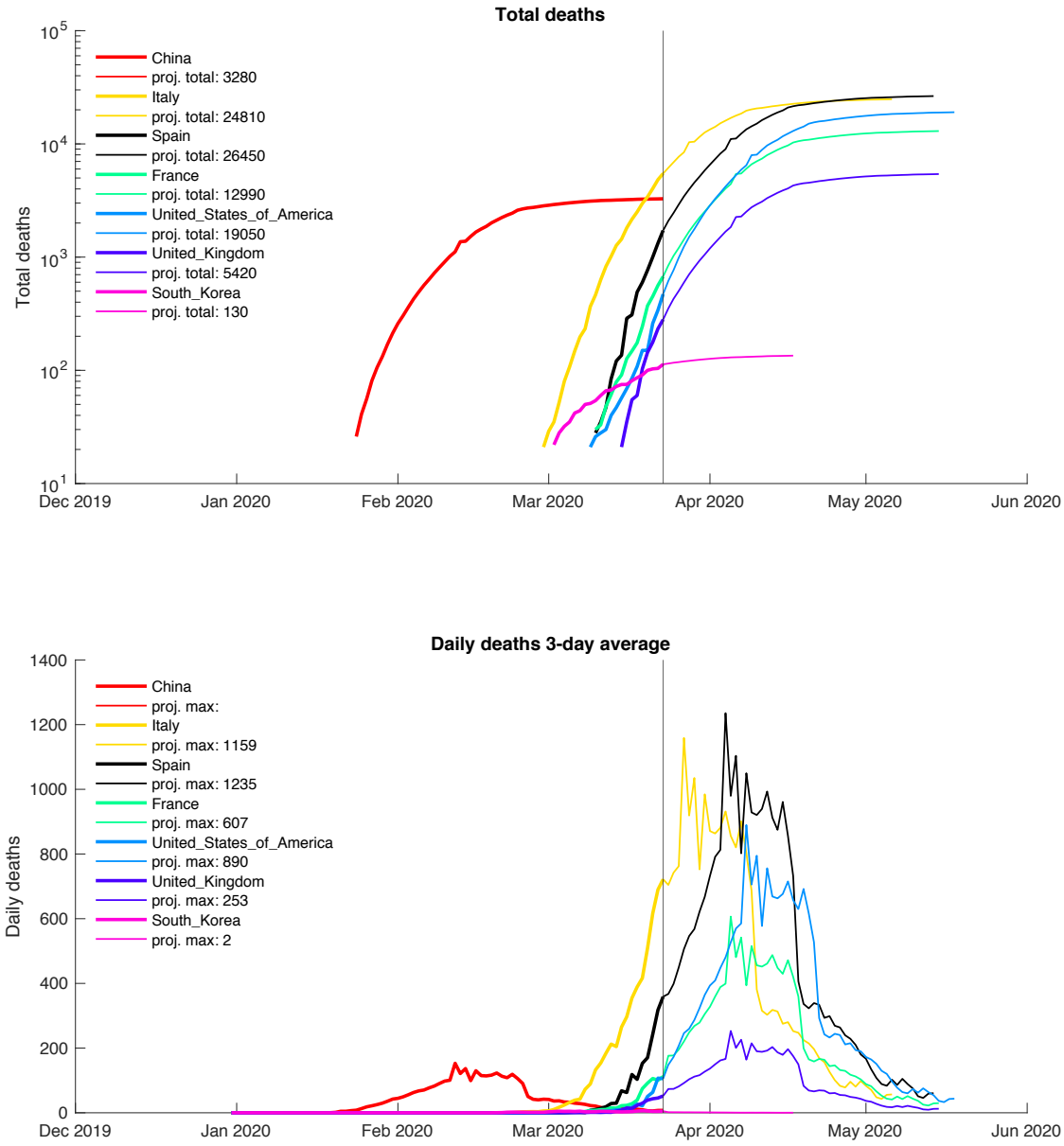

Figure 2: Estimates of the total COVID-19 deaths for the listed countries derived by following the growth trajectory of China from 21/03/2020.

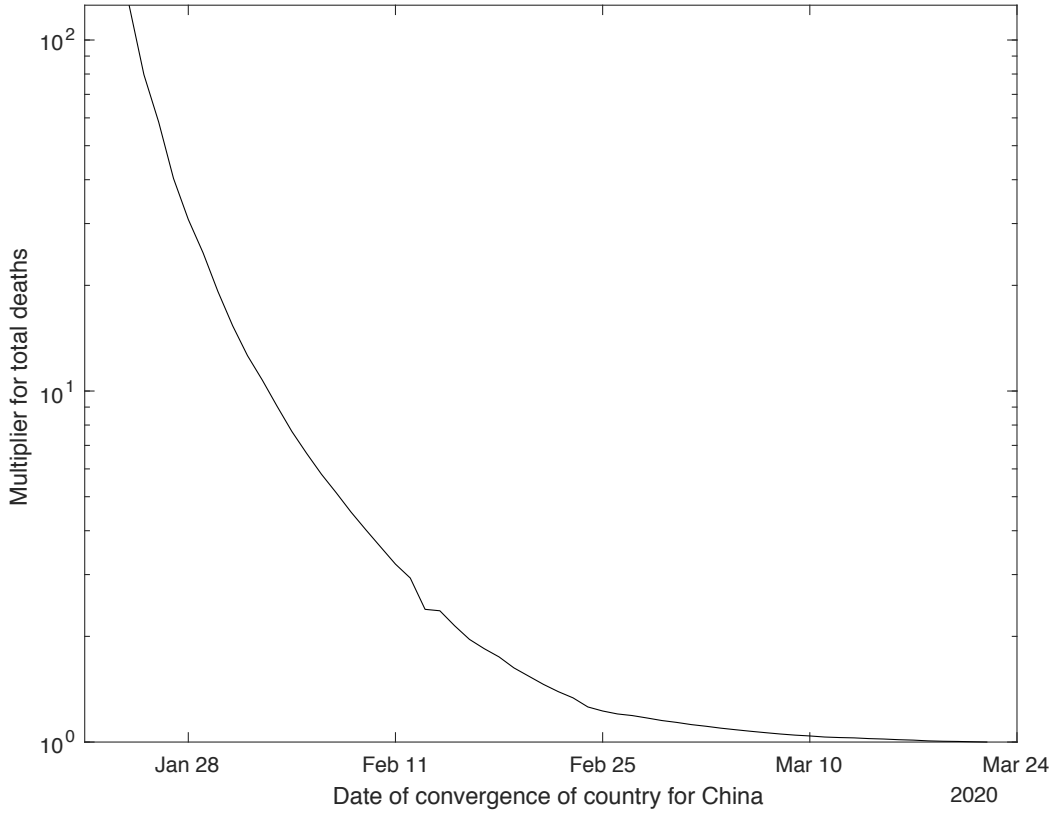

Figure 3: Multiplier for current total deaths for a country outside China to give the final total deaths, plotted as a function of the date of convergence for the Chinese dataset.

Table 1: Estimates (actual for China for 20/03/2020) of the total COVID-19 deaths and the maximum daily deaths (3-day average) based on the listed countries following the growth trajectory of China from 20/03/2020. Lower and upper sensitivities are based on an offset from the current best match to China's trajectory of plus or minus one day. The date of maximum daily deaths corresponds to the estimated value.

	Total deaths			Maximum daily deaths			
	Estimate	Lower sensitivity	Upper sensitivity	Estimate	Lower sensitivity	Upper sensitivity	Date
China	3248	Actual	to date	150	Actual	to date	23/02/2020
Italy	24800	22100	28200	1020	1030	1320	07/04/2020
Spain	26500	21800	33200	1190	1020	1550	14/04/2020
France	13000	10400	16700	650	490	780	16/04/2020
USA	19100	14600	27600	930	680	1290	17/04/2020
UK	5400	4300	7000	270	200	330	14/04/2020
South Korea	130	130	130	2	2	2	24/03/2020