Country Performance Against COVID-19: Mid-Pandemic Rankings for 35 Countries

by

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Country Performance Against COVID-19: Mid-Pandemic Rankings for 35 Countries[§]

Dean T. Jamison, Lawrence J. Lau, Kin Bing Wu and Yanyan Xiong[1]

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Abstract: The objective of this paper is to generate rankings of 35 countries on mid-pandemic performance against COVID-19 in order to facilitate identification of policy success and to inform political accountability. Selected countries each had had 5500 or more cases (collectively including 85% of the world's cases) as of 16 April 2020 and had reached 65 days into the pandemic by 21 May.

While the initial severity and end-of-pandemic performance of countries can reasonably be ranked by COVID-19 cases or deaths per million population, perhaps adjusted for age distribution or other contextual factors, for guiding policy and informing public accountability during the pandemic, we propose mid-pandemic performance rankings based on doubling time in days of the total number of cases and deaths in a country as derived over a five-day period at day 65 with days 25 and 45 calculated for comparison. Rank orderings then follow. Country doubling times on deaths correlate with those on cases, but the two rankings differ sufficiently to suggest that they capture different dimensions of performance. By days 45 and 65, mid-pandemic performance shows large (and increasing) cross-country variation, and rankings of countries by performance becomes meaningful.

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Introduction

On 31 December 2019, Chinese authorities informed the World Health Organization's (WHO) Regional Office in Beijing of cases of pneumonia of unknown etiology appearing in Wuhan, capital of Hubei Province.[2] COVID-19's subsequent upward trajectory has dominated news and political attention for the past 5 months. During this time, countries differed widely in their responses to the pandemic. Some acted quickly, others more slowly. Some adopted stringent social distancing policies, others less so. Some ramped up production and deployment of test kits and personal protection equipment, others assigned this lower priority. Do these choices matter for health and economic outcomes? Our purpose in this study is to provide performance metrics to underpin analysis of the extent to which policy choices matter.

Performance metrics serve three distinct purposes. First, by providing concrete indicators of outcomes that can be used across countries, metrics enable evidence-based assessment of both policies and the identification of good practices. Second, such measures facilitate understanding of the importance of contextual factors influencing outcomes such as age distribution of the population, population density, seasonality, local climate, or (conceivably) viral genetics.[3] Such understanding can—if timely—provide advance notification of the magnitude of the pandemic problem that may need to be addressed and help guide policy and planning in the right directions. A third purpose for performance rankings is to provide a basis for political accountability, similar to the use of measures of gross national income (GNI) per person and of employment levels in assessing economic performance.

As the principal objective of pandemic control is to save lives, it is reasonable that deaths per million population and closely related measures—like excess all-cause mortality and age-adjusted mortality or the ratio of infection and deaths of ethnic and religious minorities to that of majority—could serve as the end-of-pandemic indicators. However, such data would only be available at the end of the pademic and would provide limited guidance during the pandemic itself.

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[2] World Health Organization. "Novel Coronavirus (2019-nCoV) Situation Report–1 21 January 2020." http://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports.

[3] Forster, P., Forster, L., Renfrew, C., and Forster, M. "Phylogenetic network analysis of SARS-CoV-2 genomes." PNAS, 8 April 2020. https://doi.org/10.1073/pnas.2004999117.

For this mid-pandemic performance review, the salience of GNI growth rate (rather than its absolute size) suggests the communication value of indicators based on rates of change. At any given time, the growth rate in a country's cumulative number of cases, for example, translates into a doubling time defined as how many days it would take the cumulative number of cases to double if that rate were to continue. The longer the doubling time, the better a country is doing. Our purpose in this paper is to provide a framework to analyze mid-pandemic performance based on doubling times for both cases and deaths, which can be extended to other countries and continents as they are more exposed to the pandemic.

Data and Methods

Country selection and data

Our selection criteria for country inclusion were: first, countries accounting for a significant percentage of global cases (with 5500 cumulative cases or more at individual country level) as of 16 April when the study began, and second, country data being available long enough into the pandemic so that days 45 and 65 performance could be calculated. Our choice of days 45 and 65 not further along for this initial evaluation was both to provide a baseline and to ensure that a sufficient number of countries from different continents could be selected for the study. This resulted in the selection of 35 countries from all continents, except Africa, which accounted for 85% of the global cumulative cases and 84% of global cumulative deaths as of April 16.[4] The diversity of these 35 countries can shed light on whether their development stages and income levels have bearings on their performance. We also identified and studied four countries which had have very low cumulative case loads (ranging from 268 to 2207) and low deaths total (from 0 to 105) because of their success in pandemic control. In addition, we studied two well performing countries which had experienced reversal.

We chose our performance metrics based on three criteria: they are available in current cross-country data series, can serve directly as indicators (after adjustment for population size if necessary) or as a derived indicator, and most importantly, can adequately reflect relevant dimensions of performance. We explored various sources that provide comprehensive coverage of the world, including those from WHO's daily "Situation Reports" and Johns Hopkins

[4] Worldometer Coronavirus Updates, 16 April 2020, https://www.worldometers.info/.

University's Coronavirus Resource Center. The cases and deaths reported in these two sources and Worldometer are similar for all of our selected countries, except Spain where Worldometer included both cases confirmed by PCR tests and anti-body tests after the middle of April. We settled on Worldometer for pandemic data because it is in real time, it presents data visually in graphs, and it provides useful information beyond the statistics on cases and deaths, including the number recovered, number in serious conditions, cases and deaths per million population, and number of tests per million population. Importantly, Worldometer provides links to its sources which are usually official websites and occasional research and news articles. From data underlying its graphs, we constructed time series on our included countries. We checked all the sources of Worldometer, and used press reports, for example from Turkey, and journal articles to provide context to the numbers.[5]

Data on China came from its National Health Commission.[6] As China revised its cases and deaths statistics on Wuhan and Hubei, we incorporated the revisions and smoothed the data upwardly.[7, 8] We also included data from Hubei Province of China, Lombardy Department of Italy, and New York State of USA in order to illustrate the magnitude of within country variation. Separate data sources provided needed information on Lombardy.[9] New York State data came from Worldometer.

Each country's start date for its pandemic was defined to be the first day for which the cumulative number of cases had reached 20 or more. The emergence of 20 cases in a country —along with the WHO's 30 January 2020 declaration of COVID-19 as a public health emergency of international concern—would have provided clear indication to a country's political leadership of the need for action. We measure the initial severity of the pandemic in a country by its day 25 number of cases per million population. The initial severity and the evolution of doubling time in mid-pandemic determine the end-of-pandemic performance.

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[5] Toperich, S. "Turkey emerges as key player in global Covid-19 flight." *The Hill,* 14 April 2020. http://www.thehill.com.
[6] Data from China were taken from "Daily Briefing on coronavirus cases in China" in China's National Health Commission website. http://en.nhc.gov.cn
[7] Lau, L.J., and Xiong, Y., March 2020. "Don't Panic, be cautious, and together we can stop the Coronavirus epidemic." *Asia Pacific Biotech News,* Special Issue 1, Pp. 90–107. doi: s0219030320001202. Preprint available 14 February, 2020.
[8] Lau, L.J., and Xiong, Y. May 2020. Appendix 1: corrections and adjustments of the data. In Lau, L.J., and Xiong, Y., *The COVID-19 Epidemic in China*, Singapore, World Scientific Publishing Company, forthcoming, 2020.
[9] Lombardy data came from Dipartimento della Protezione Civil (of Italy). https://github.com/pcm-dpc/COVID-19/tree/master/dati-regioni. Accessed on 1-6 May 2020.

For our study, we started our data collection on April 16 and completed our analysis by May 21. We consider the pandemic under control when the countries have fewer than 20 cases per day for 14 days or an average of 280 or fewer cases in the preceding 14 days. The pandemic under control means that the cases are few enough for countries to use testing, contact tracing and quarantine of the infected and close contacts to manage the pandemic with limited adverse impact on people's livelihood, education and the economy. Until a vaccine is available to inoculate a sufficient large portion of world population, the pandemic is likely to be with us continuously. Any substantial re-emergence of cases or deaths after the date of "under control" could be interpreted as marking the start of a second wave.

Shortcomings in data available mid-pandemic receive increasing scrutiny in the press and within the academic community. COVID-19 deaths themselves appear in most countries to need upward adjustment as more data come in.[10, 11] In part this results from an increasingly understood gap between observed increases in all-cause mortality and reported COVID-19 mortality.[12] This can result both from the underreporting of COVID-19 deaths and from non-coronavirus mortality rate changes that are caused by the pandemic or the response to it. Although we recognize the potential challenge, we believe it is still worthwhile to work with available although imperfect data in order to come up with timely measures to inform policy.

Data on cases and deaths by age remain to be systematically reported and, in consequence, this analysis uses an overall measure of mortality rather than age-specific ones. Instituto de Salud Carlos III of Spain reports data on the percent of deaths falling into each age band and the Spanish data illustrate how important this can be.[13] Combining the age distribution of COVID-19 deaths in Spain with (separate) information on the age distribution of the population allows calculation of deaths per million population by age group. By 6 May the Spanish population as a whole had had 550 deaths from COVID-19 per million population, but among the population over age 70 the rate would have been 3,100 per million, while for under

[10] Speigelhalter, D. "Coronavirus deaths: how does Britain compare with other countries?" *The Guardian*, 30 April, 2020.
[11] Burn-Murdoch, J., Romei, V., and Giles, C. "Global Coronavirus death toll could be 60% higher than reported." *Financial Times*, 26 April, 2020.
[12] Brown, E., Ba Tran, A., Reinhard, B. and Ulmanu, M. U.S. deaths soared in early weeks of pandemic, far exceeding number attributed to covid-19. *Washington Post*, 27 April, 2020.
[13] Instituto de Salud Carlos III. *Informe sobre la sitiación de COVID-19 en España.* Informe COVID-19 no. 25. 23 April, 2020. Accessed from www.isciii.es on 25 April, 2020.

70 years of age, it would have been 89 per million, a ratio of 35 to 1. The comparable ratio for cases was 3 to 1.

Evidence is also increasingly available that suggests substantial ethnic differences in case and fatality rates.[14] For example, our calculation shows that in New York City, the ratios of deaths per million to Whites are 1.5 for Blacks, 1.4 for Hispanics, and 0.6 for Asians.[15] This suggests value in constructing separate performance measures by ethnicity, as well as for elderly and younger age groups, to complement the overall performance metric that we use. Unit the requisite data become available, analysis like ours will be based on population-level data. All population data come from the World Bank.[16]

Methods

We use the trajectories of the cumulative numbers of cases and deaths to assess country performance: how quickly, at any point in time, is a country flattening the rise in cumulative cases (or deaths) over time? The more nearly flat the cumulative curve is at a point in time the longer it will take for the number of cumulative cases or deaths to double, and our metrics of performance at time t are the doubling times at time t of cases and of deaths, $DT_c(t)$ and $DT_d(t)$. Time is measured in days from the start date, defined as the first date for which the cumulative number of cases is reported as 20 or more in a country. $DT_c(45)$ and $DT_d(45)$ are our headline performance measures.

Doubling time is calculated in two steps. Let C(t) and D(t) be the cumulative number of cases and of deaths at time t. Then the average daily rate of growth in the cumulative number of cases, r, is calculated for the five-day period centered at t. Use of a 5-day period reduces the influence of the cumulative number on any particular date on the rate of growth. In any case, cumulative data are by their nature, already quite smooth. The value for r is given by:

$$r(t) = \ln[C(t+2) / C(t-2)] /4.$$

[14] Bhala, N., Curry, G., Martineau, A. R., Agyemang, C., and Bhopal, R. "Sharpening the global focus on ethnicity and race in the time of COVID-19." *The Lancet*, 8 May 2020.

[15] https://covid19tracker.health.ny.gov. Accessed on 5 May 2020.

[16] World Development Indicators database, World Bank, 23 December, 2019, http://databank.worldbank.org.

From r, doubling time follows:

$DT_c(t) = \ln 2/r(t)$.

Doubling times for deaths were similarly calculated.

We explored several alternatives to doubling time involving first and second derivatives of C(t). Doubling time emerged as the most intuitive and informative.

Results

Table 1 provides the context of the pandemic. It presents information on a country's population, start date, cumulative cases and deaths per million population on days 25, 45 and 65. The table shows that initial severity (on day 25), measured in cumulative cases per million population, varies enormously across countries. It is natural to expect *initial* severity in less populous countries to be higher than in more populous ones simply because of larger denominators, and because the initial penetration of the pandemic is likely to be quite local. This pattern is evident in the table. Initial severity tends to be exceptionally high in many European countries, particularly in Austria, Belgium, Ireland and Switzerland. Even good mid-pandemic performance can only partially compensate in influencing end-of-pandemic mortality per million population. Switzerland, for example, had the highest initial severity of any of the 35 countries. Its initial severity was substantially—but incompletely—compensated for by excellent mid-pademic performance. Germany appears likely to achieve good end-of-pandemic performance by combining (relatively) low initial severity with good mid-pandemic performance.

Table 1: State of the COVID-19 pandemic in 35 selected countries[a]

Country	Start date[b]	Population (millions)	Cumulative cases per million population			Cumulative deaths per million population		
			Day 25[c]	Day 45	Day 65	Day 25	Day 45	Day 65
Australia	22-Feb	25	18	236	269	0.2	2	3
Austria	3-Mar	9	855	1608	1743	6.4	46	68
Belgium	4-Mar	11.4	800	3164	4503	31	452	737
Brazil	8-Mar	210	33	205	805	1.2	13	55
Canada	29-Feb	37	75	692	1603	0.7	21	99
Chile	11-Mar	18.7	223	658	1981	1.4	9	20
China	1-Jan	1395	2.2	48	58	0.06	1.5	3
Czechia	7-Mar	10.3	321	670	789	3	19	27
Denmark	6-Mar	5.8	444	1273	1779	13	61	91
France	27-Feb	67	239	1764	2489	10	206	367
Germany	26-Feb	83	269	1472	1977	0.8	31	80
India	4-Mar	1353	0.7	11	42	0.02	0.4	1.4
Indonesia	10-Mar	268	7.4	29	58	0.7	2.4	3.8
Iran	22-Feb	83	195	729	1090	12	45	69
Ireland	8-Mar	4.9	703	3273	4721	17	149	299
Italy	21-Feb	60.4	463	2135	3234	36	263	437
Israel	6-Mar	8.9	528	1516	1849	1.8	19	28
Japan	1-Feb	127	1	7	29	0.01	0.2	0.7
Korea, Rep. of	6-Feb	51.6	72	169	201	0.3	2	4
Mexico	14-Mar	127	19	116	371	1	11	40
Netherlands	3-Mar	17.2	499	1696	2398	32	192	302
Norway	2-Mar	5.4	624	1259	1473	2.6	28	40
Pakistan	11-Mar	212	13	56	169	0.2	1.2	3.6
Peru	12-Mar	32	71	792	2640	2.6	22	74
Poland	10-Mar	38	89	277	464	2	12	23
Portugal	7-Mar	10.3	723	2026	2678	16	71	110
Romania	10-Mar	19.5	163	518	833	7	28	54
Russia	9-Mar	145	24	400	1602	0.2	3.5	15
Saudi Arabia	9-Mar	34	55	376	1263	0.6	3.4	8
Spain	27-Feb	47	612	3469	5170	38	353	528
Sweden	3-Mar	10	304	1242	2368	9	132	291
Switzerland	1-Mar	8.6	1267	3016	3486	18	137	207
Turkey	16-Mar	83	509	1417	1828	11	37	51
UK	28-Feb	67	99	1258	2720	5	183	420
USA	21-Feb	328	14	1048	2929	0.3	36	165

Table 1 continued

Subnational regions	Start date[b]	Population (millions)	Cumulative cases per million population			Cumulative deaths per million population		
			Day 25	Day 45	Day 65	Day 25	Day 45	Day 65
China:								
Hubei, China	1-Jan	60	35	924	1148	1.3	34	69
China outside Hubei	20-Jan	1336	9	10	10	0.05	0.08	0.1
Italy:								
Lombardy, Italy	21-Feb	10.1	1450	4996	7126	141	882	1314
Italy outside Lombardy	21-Feb	50.3	228	1438	2420	15	133	261
USA:								
New York State, USA	5-Mar	19.5	3066	12335	17611	61	879	1373
USA outside New York State	21-Feb	309	11	687	2183	0.3	18	105

[a] Sources: Time series data on countries and New York State from http//www.worldometers.info. Population data from World Development database, World Bank, 23 December 2019. China and Hubei data from China's National Health Commission's "Daily Briefing on novel coronavirus cases in China". http://en.nhc.gov.cn. Lombardy data from github.com/pcm-dpc/covid-19/tree/master/dati-andamento-nazionale.

[b] The start date is defined as the first day when 20 or more cumulative cases were reported. In China, the start date of Jan 1, 2020 came from WHO's Situation Report 1, which states that the Chinese authorities reported a total of 44 cases from 31 December 2019 through 3 January 2020. http://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports. Worldometer uses Greenwich Mean Time (GMT) and this table retains that convention. Sources from China reported in Chinese local time, which would be one day later.

[c] We define the initial severity of the pandemic to be a country's number of cases per million population at day 25.

To provide context, table 1 includes entries for subnational regions in three key countries to illustrate how pandemic impact differs between the epicenters and the rest of the country. The first is China - Hubei Province and China outside Hubei. ("China" as used in this paper denotes the Mainland of China.) The pandemic in China began in December 2019 in the city of Wuhan, which is Hubei Province's capital city. By 1 January 2020, there were 44 reported cases[17] and the first death was reported on 11 January.[18] Table 1 shows that the cumulative number of deaths per million in China was 3, that in Hubei was 76, and that in China outside Hubei was 0.1. In Italy, Lombardy, like Hubei, was severely overwhelmed, with 1314 deaths per million population by day 65. Outside Lombardy, Italy's deaths per million was 261, compared with 437 in Italy as a whole. In New York State, the number of deaths per million was 1373, compared with 105 deaths per million in USA outside New York State and

[17] World Health Organization. "Novel Coronavirus (2019-nCoV) Situation Report–1 21 January 2020." http://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports.

[18] Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J. Hu, Y., Zhang, L., and others. "Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China." *The Lancet*, vol. 395, 15 February, 2020. Pp. 497–506.

165 in USA as a whole. Separating subnational regions from a country as whole sheds light on how epicenters within a country may or may not drive the national evolution of the pandemic. Our examples of Hubei, Lombardy and New York State provide only a starting point.

Table 2 shows our main findings. The 35 countries are ordered from highest to lowest (best to worst) in doubling times for cases and deaths on day 65, with those in days 25 and 45 along side for comparison. Figs 1A and 1B graphically illustrate the wide range in performance for cases and for deaths at days 65 and 45, but much less so for day 25. In general, countries improved substantially between these intervals, although with marked cross-country variation. Country performance on deaths tracks performance on cases, but only imperfectly. For 3 of 35 countries, the performance rank for deaths differed by more than 10 from its rank on cases. Maintaining separate indicators is thus of value.

Table 2: Mid-pandemic performance of 35 selected countries

		Cumulative cases, days to double					Cumulative deaths, days to double		
Rankings	Country	Day 25	Day 45	Day 65	Rankings	Country	Day 25	Day 45	Day 65
1	China	2.3	16.8	586.0	1	Austria	2.7	19.4	120.0
2	Israel	5.3	38.9	365.0	2	Switzerland	4.2	18.9	115.0
3	Switzerland	7.2	54.9	342.0	3	Denmark	5.9	28.8	111.0
4	Australia	3.0	32.0	295.0	4	Turkey	6.6	23.8	106.7
5	Austria	6.1	90.0	285.0	5	Norway	4.3	15.1	99.0
6	Korea, Rep. of	3.5	61.3	226.0	6	France	3.1	13.6	84.0
7	France	4.9	19.3	204.0	7	Ireland	3.5	10.5	80.0
8	Czechia	9.0	36.8	187.0	8	Czechia	2.8	19.9	77.0
9	Portugal	6.7	25.1	119.0	9	China	2.0	8.1	73.0
10	Norway	8.2	56.2	118.0	10	Spain	2.7	19.9	69.4
11	Germany	4.3	22.9	110.0	11	Portugal	4.9	20.8	64.4
12	Turkey	6.5	32.1	102.1	12	Iran	4.8	19.0	52.4
13	Ireland	7.2	19.3	100.0	13	Netherlands	3.6	13.8	52.0
14	Netherlands	5.3	19.6	87.0	14	Italy	3.8	18.0	51.0
15	Belgium	4.3	20.3	69.0	15	Germany	2.7	11.0	46.3
16	Denmark	8.0	32.9	66.4	16	Korea, Rep. of	3.6	14.0	41.0
17	Spain	4.5	26.5	65.6	17	Belgium	3.3	11.2	40.7
18	Italy	5.3	22.0	57.2	18	UK	4.0	10.3	39.0
19	Iran	10.0	18.8	57.0	19	Israel	3.6	14.0	38.3
20	Romania	6.1	19.8	48.6	20	Indonesia	12.0	17.8	33.7
21	Poland	5.9	20.6	36.5	21	Poland	4.0	10.4	32.0
22	Sweden	7.3	14.7	26.1	22	Romania	5.6	14.8	31.6
23	UK	4.3	11.5	26.0	23	Australia	8.2	5.4	26.0
24	Canada	2.7	14.1	23.2	24	USA	2.6	4.9	22.6
25	USA	2.3	7.6	21.2	25	Sweden	4.8	7.3	20.3
26	Indonesia	9.1	14.8	19.1	26	Saudi Arabia	2.6	13.2	20.0
27	Pakistan	6.3	9.9	16.1	27	Mexico	4.4	13.8	19.8
28	Saudi Arabia	8.3	7.6	15.2	28	Pakistan	6.3	9.8	19.6
29	Russia	3.9	7.4	15.0	29	Canada	4.0	6.4	15.8
30	Peru	4.5	8.8	14.6	30	Russia	3.0	6.6	15.0
31	Brazil	4.4	11.2	14.4	31	Peru	4.9	8.9	13.9
32	Mexico	5.3	10.5	14.4	32	Brazil	3.5	9.3	13.2
33	India	5.1	7.8	11.6	33	India	5.9	9.9	12.8
34	Chile	8.0	16.7	10.4	34	Chile	3.8	16.6	12.1
35	Japan	7.3	21.6	7.5	35	Japan	2.0	10.0	9.3

Table 2 continued:

Subnatonal level:	Cumulative cases, days to double Day 25	Day 45	Day 65		Cumulative deaths, days to double Day 25	Day 45	Day 65
China:				China:			
Hubei Province	3	15	498	Hubei Province	2	8	71
China outside Hubei	34	5118	8971	China outside Hubei	7	153	8971
Italy:				Italy:			
Lombardy	7	29	60	Lombardy	4	21	72
Italy outside Lombardy	4	20	56	Italy outside Lombardy	4	15	39
USA:				USA:			
New York State	6	26	98	New York State	3	17	107
USA outside New York State	3	7	19	USA outside New York State	3	8	18

Fig. 1A: Doubling time in cases in days 25, 45 and 65 in 35 countries

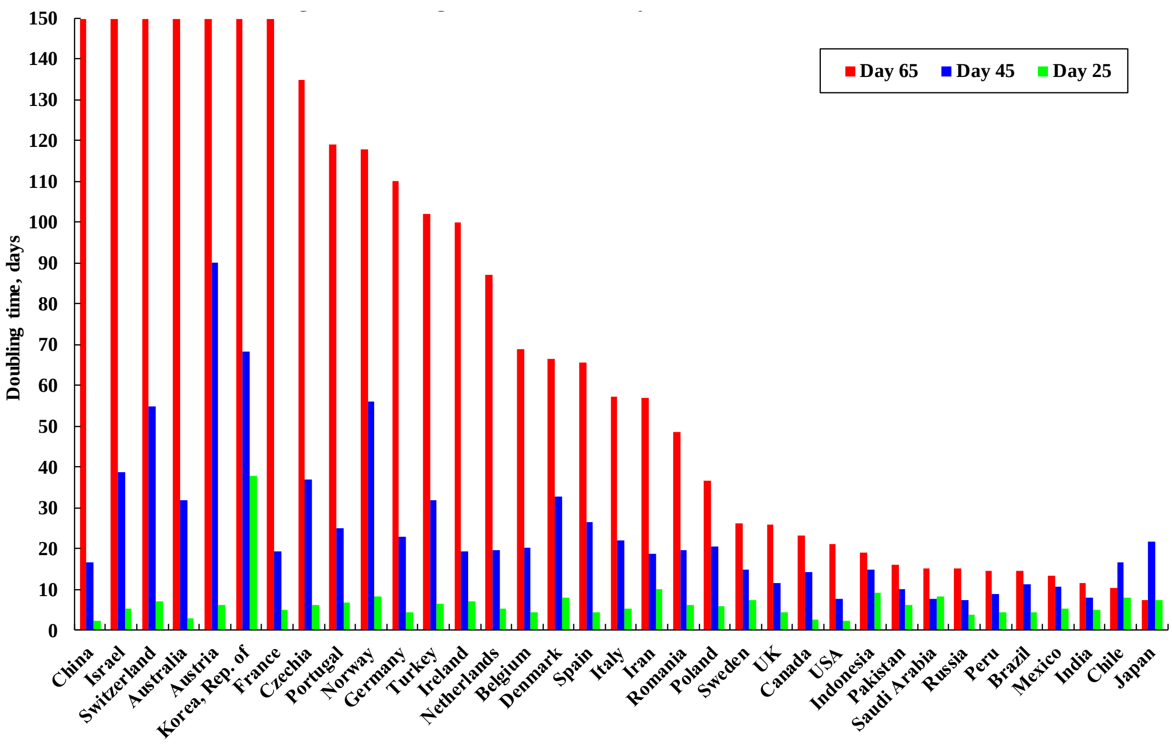
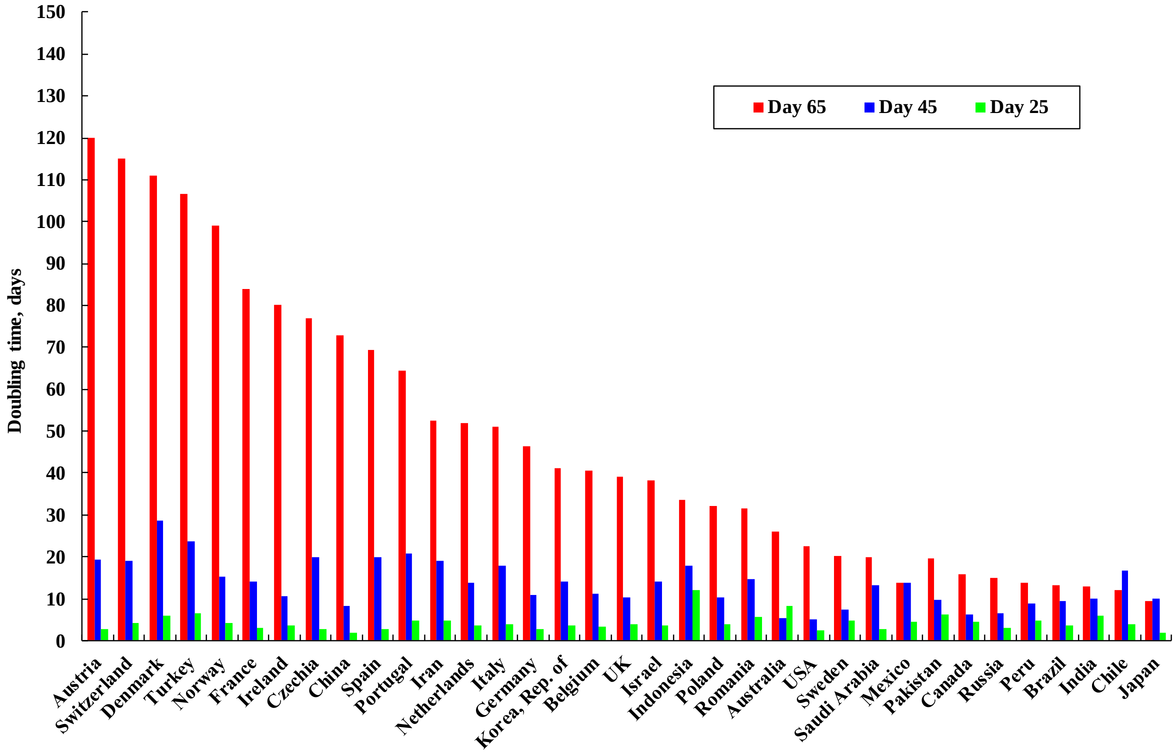


Fig. 1B: Doubling time in deaths in days 25, 45 and 65 in 35 countries



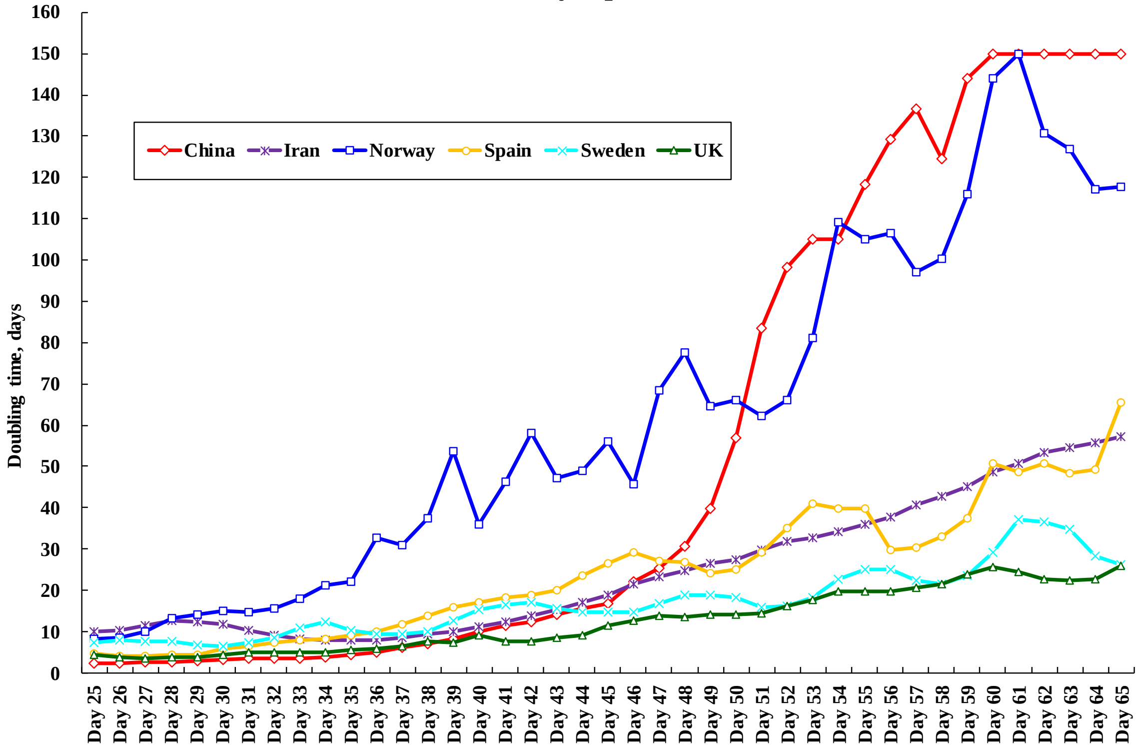
What is most striking is that by day 65, 8 countries—China, Israel, Switzerland, Australia, Austria, Republic of Korea, France and Czechia—have raised the doubling time in cases well above150 days, beyond which doubling time ceases to be a useful indicator because of the small number of cases or deaths then being incurred. For deaths, no country has reached the doubling time of 150 days by day 65 because deaths of previously sick patients continue even after cases have been falling. However, Austria, Switzerland, Denmark, and Turkey attained the doubling time above 100 days by day 65, meaning it will take over 3 months for the deaths to double.

By day 65 most European countries had raised their doubling time in cases and deaths very substantially. Indeed, 6 of the 10 best performing countries on cases and 8 of the top 10 on deaths are European. The UK and Sweden were exceptions, with each having about 22 days of doubling time for cases. Sweden's doubling time for deaths was less than a quarter of that of neighboring Norway. Sweden pursued a policy of minimum interventions in sharp contrast to Norway's much stricter measures. UK initially pursued a policy to attain herd immunity and then changed course.

Among the four countries from the Middle East, both Turkey and Iran performed well with high doubling times in both cases and deaths by day 65. Israel performed very well on cases. Two South Asian countries – India and Pakistan- face rapidly surging doubling time for cases and deaths. The 6 included countries from the Western Hemisphere ranked in the bottom third of all countries on both cases and deaths. Chile fell sharply in the ranking between days 45 and 65, while the USA moved somewhat up from its previous position at the bottom of the list.

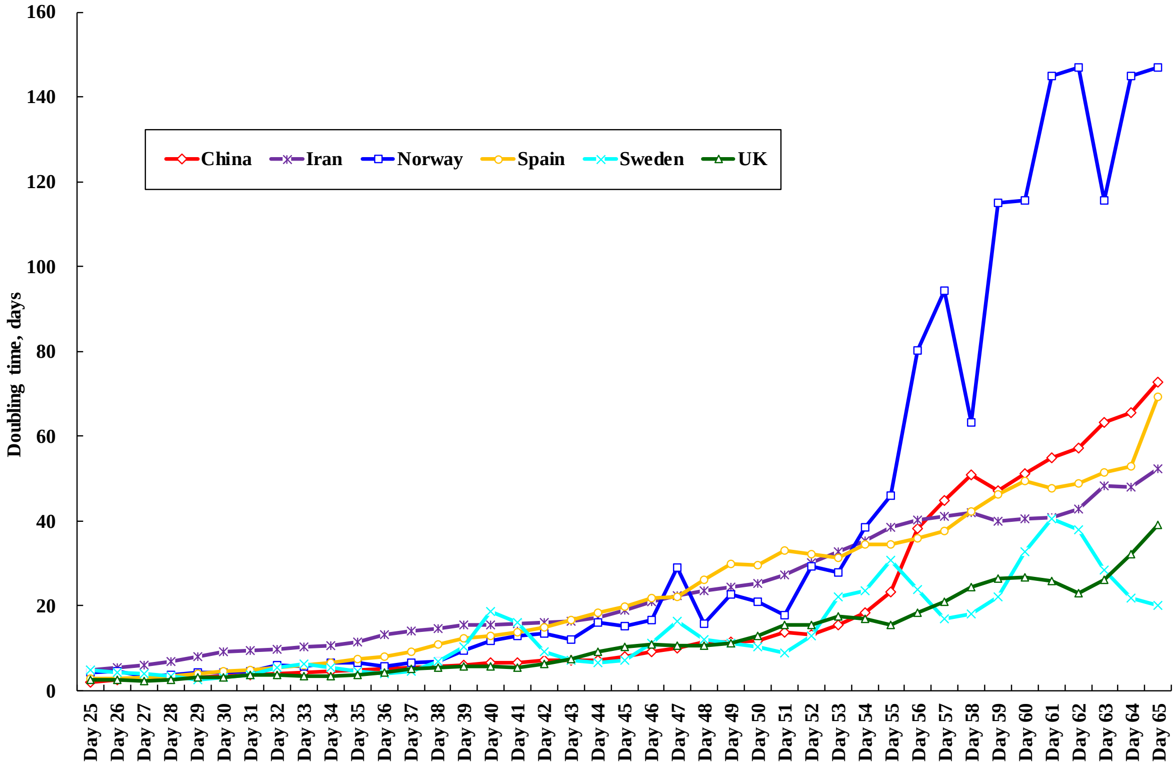
Figure 2 displays the evolution of doubling time for 6 countries that span a range of performance levels. Figure 2A shows cases and 2B shows deaths between days 25 and 65. Doubling times in cases and deaths for Iran and Spain track each other closely, as do those for Sweden and the UK, albeit at a lower level of performance. The figure shows China and Norway very rapidly increasing their doubling times for cases and, to a lesser extent, for deaths. China experienced an abrupt upward change in performance on cases after day 45. But China's improvement is so large that it is off the chart and we capped its data at the doubling time of 150 days in line with our general observation that doubling time becomes a less specific indicator above the value of about 150. Improvements in doubling times for deaths lagged somewhat behind, with Norway showing a rise beginning on day 50 and China showing a similar rise from day 55.

Fig. 2A: Doubling time in cases between days 25 and 65 in China, Iran, Norway, Spain, Sweden and UK



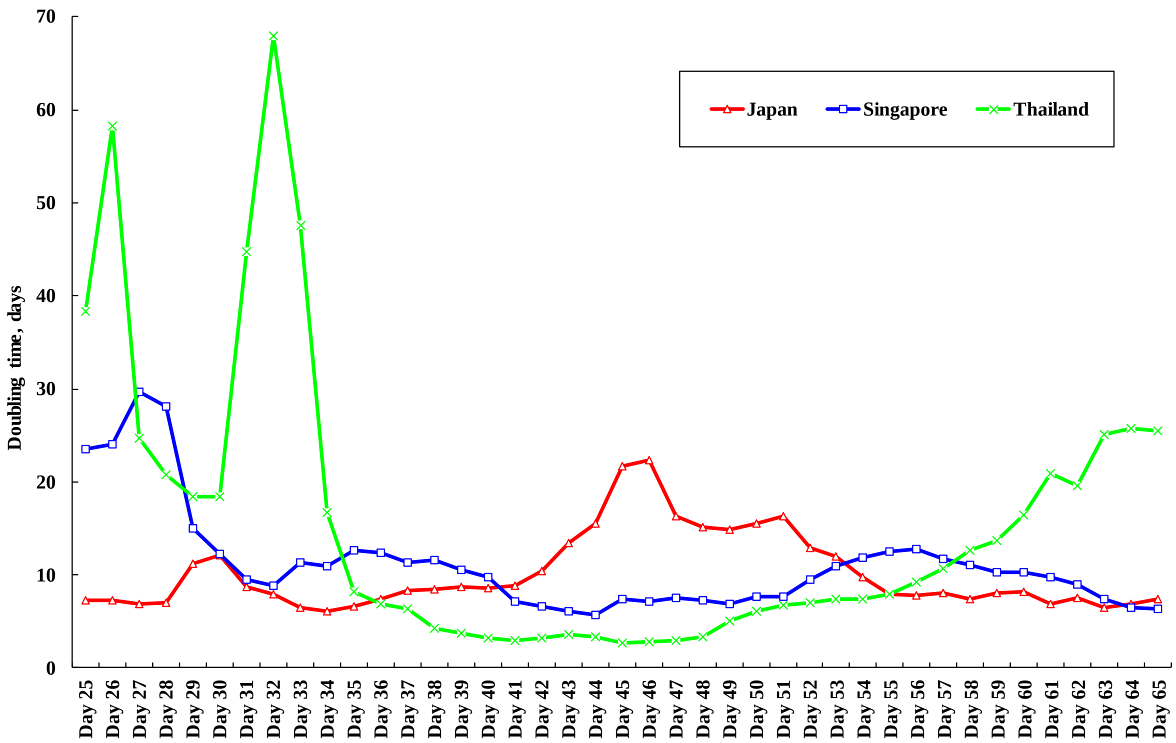
Note: Doubling time is capped at 150 days. See Table 2 for details.

Fig. 2B: Doubling time for deaths between days 25 and 65 in China, Iran, Norway, Spain, Sweden and UK



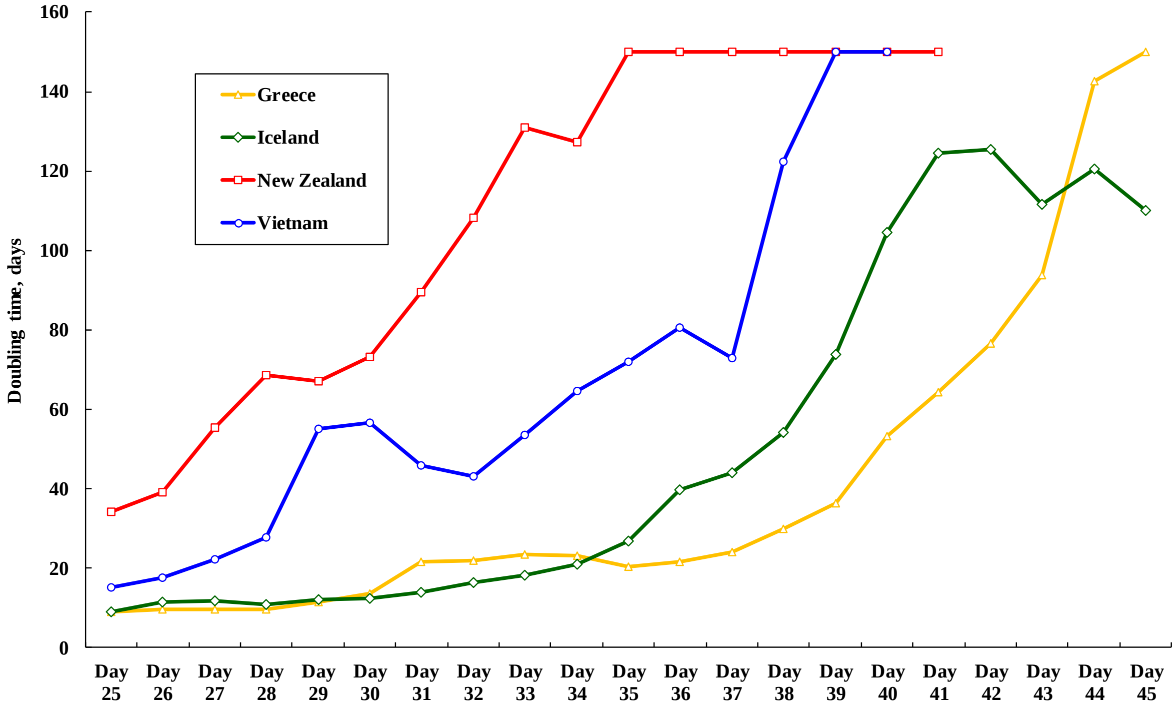
Continuation of short doubling times will erode the advantage of Japan's exceptionally low initial severity (table 1). Japan ranked lowest in table 2 because Japan experienced actual declines in doubling times between days 45 and 65. New cases started to surge after day 54, peaking on day 71 before resuming a decline. The possibility of reversal is well illustrated by two additional countries that on the whole performed well, Thailand and Singapore. Thailand's new cases reached a plateau between days 48 and 64, before declining gradually. Singapore saw a surge on day 61, before gradually falling after day 76. The resurgence of the diseases in these high performing countries show just how challenging it is to maintain control of the pandemic (fig 3).

Fig. 3: Doubling time in cases in Japan, Singapore and Thailand



Four other successful countries with cases too low for inclusion in our main analysis – Greece, Iceland, New Zealand and Vietnam – had doubling time for cases similar to high performing countries on our performance metric (fig 4). Vietnam had no new cases between days 40 and 48, and New Zealand reached the doubling time of 150 by day 35, and Vietnam by day 39. As previously noted, when numbers of cases are (or become) small, doubling time metrics become volatile and lose meaning. The metric performs best in mid-pandemic and with countries (unlike those shown in fig 2) where the numbers of cases or deaths have been large.

Fig. 4: Doubling time in cases between days 25 and 45 in Greece, Iceland, New Zealand and Vietnam



Note: Doubling time is capped at 150 days.

By mid-pandemic, it is clear that a country's performance is not pre-determined by its developmental or income level. How countries respond, whether initially or at mid-term, can change the course of the pandemic.

Discussion

There are a number of limitations to the analysis here. First, as previously discussed, data validity remains variable across countries and time. COVID-19 data quality is much discussed by others and we simply note our study's possible sensitivity to data quality and our expectation that data quality will improve. Second, available resources lack consistent, cross country data on mortality by age and ethnicity. Our study is thus limited to population-wide data on cases and deaths. Third, subnational data series though not now widely available arguably hold the keys to improved understanding drivers of national level performance. A fourth limitation is that countries that do exceptionally well in preventing an epidemic may not appear among the countries we rank because of paucity of cases and deaths. Their experiences are worth learning from but different methods are needed to identify them. Fifth, a strong possibility exists for a pandemic with multiple waves.[19] Our study is limited to assessment of performance only in the first wave. Finally, doubling times at day 65 provide only a mid-course snapshot. We view these day 65 rankings as a starting point for tracking mid-pandemic performance over time rather than an end point.

The broad spread in performance across countries can prove a basis for improved political accountability, for identifying good practices and for the purpose of understanding determinants. Along with its January 30 proclamation of a public health emergency of international concern, WHO conveyed an assessment that specific, timely, and well understood control measures are likely to interrupt transmission.[20] Successful country examples of high and increasing doubling times confirm this assessment. Performance differences may result from many factors including delay in implementation of response, initial preparedness as, for example, reported by Metabiota,[21] stringency of national response as reported by the Blavatnik School at Oxford,[22] or many others. Our purpose in this study, however, is not to assess determinants but rather to provide country rankings to facilitate analysis of determinants and to inform political accountability.

[19] Kissler, S., Tedijanto, C., Goldstein, E., Grad, Y., and Lipsitch, M. "Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period." *Science*, 14 April 2020. Doi: 10.1126. *Science*. abb5793.
[20] World Health Organization. "Novel Coronavirus (2019- nCov) Situation Report–11 31 January 2020." http://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports.
[21]Oppenheim, B., Gallivan, M., Madhav, N. and others. "Assessing global preparedness for the next pandemic: development and application of an Epidemic Preparedness Index." *BMJ Global Health*, 2019, v.4.
[22]Hale, T., Petherick, A., Phillips, T., and Webster, S. "Variation in government response to COVID-19, version 4.0." April 2020. Oxford University, Blavatnik School of Government Working Paper Series, BSG-WP-2020/31.