Title: A pragmatic model to forecast the COVID-19 epidemic in different countries and allowing for daily updates

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Abstract

Due to high infections rates and a high death toll of the COVID-19 pandemic, it is important to have daily updated forecasted estimates for the next weeks in order to allocate the scare resources as good as possible. We propose a pragmatic model to forecast the COVID-19 epidemic by applying a mixture normal distribution to open accessible WHO data. We specified a simple joint model on data from 20 countries with number of confirmed COVID-19 infections and number of COVID-19 deaths. We found that the duration of an epidemic wave (99% of total size) was usually between 45 – 48 days. Using data up to April 6, 2020, we found in six of 20 counties two waves, spaced between 21 and 47 days. In China and Korea the first wave was bigger, and in Denmark, Iran, Japan, and Sweden the second wave was stronger. Lag time between time trends in confirmed infections and time trends in deaths varied between 3.1 and 9.5 days. We obtained a good fit between observed and modelled data in almost all countries. In about halve of the countries the highest peak of the COVID-19 epidemic had been reached until April 6, 2020. Among the 20 countries, it is predicted that the USA will reach the highest numbers of confirmed infections (653 683 – 802 205) and number of deaths (36 591 – 53 286). Taken together, for many countries reasonable and up-to-date forecasting seems to be feasible. This method therefore bears a high potential for assisting decision makers to adjust the measures aiming at reducing the spread of the virus appropriately.

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Introduction

High infection rates and a high death toll due to the COVID-19 pandemic have been observed in many counties. Accordingly, various measures have been introduced to control the COVID-19 epidemic, and these measures are accompanied by substantial restrictions both for individuals and the society as a whole in many countries. Therefore, it would be of great interest for good and updated estimates based on the most recent data on how the epidemic will develop in the near future, because this information is a prerequisite to adjust the measures limiting the spread of the virus appropriately.

It is well known that the COVID-19 originated in Hubei, a province of China, with first official recognition of a new virus in January 7, 2020. Since January 21, 2020 the World Health Organization (WHO) publishes a daily Situation Reports of the Coronavirus disease 2019 (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports). This daily report includes the number of confirmed infections and number of deaths by country. Although the incidence rates for infections and the ratio between number of infections and number of deaths varies substantially between countries, there are strong similarities between the time trends on country level. Evidence so far, based on the existing data sources, suggests that the (first) wave of the epidemic can be approximated by a unimodal distribution.

Therefore, we propose a pragmatic model that allows for daily updated forecasts of the regional spread of the pandemic, and that is based on the following assumptions: the development of number of daily confirmed infections as well as the number of daily deaths can be described by a normal distribution, where there is a certain time lag of the latter. Obviously, the start of the epidemic as well as the size of the epidemic are country specific. But as there is a similar pattern how governments react to the COVID-19 epidemic (first trying to ignoring them, then introducing similar steps of measures to control the epidemic), we assume that the duration of the epidemic waves are also similar across countries. In those countries, where the data indicate two waves (i.e. China, Denmark, Iran, Japan, Korea, and Sweden) we applied a mixture of two normal distributions (where the proportional size of the waves and the time lag between the maximum peak are estimated, but standard deviation is assumed to be identical). Additionally, we use only data from the WHO reports if the cumulative number of confirmed COVID-19 infections were 100 cases or higher, as this probably indicates onset of local transmission.

As for some countries WHO data are not updated every day and given that it is almost impossible to collect such data with delays of less than 24 hours, we used moving averages with a time window of 5 days for analysis in order to address such ‘data spikes’ that are most probably artificial and due to the collection and reporting process. There was also a change in definition how to report confirmed cases in China resulting in an extreme peak in the WHO data. Moreover, it is also probable that availability of tests and installing routes of information procedures may change over time in a country. Despite these biases, we think that our simple and pragmatic model will result in useful forecasts that can be updated every day due to its simplicity, and that can easily be applied on data on a national or regional level.

For analysis, we used data of 20 countries and applied a joint model, with number of confirmed infections and number of deaths as dependent variable. We used a binomial distribution and accounted for model deviations by variance-covariance matrix adjustment. On April 6, 2020, the model could use 1 414 data points to estimate 76 parameters in total.

Results

The application of our pragmatic COVID-19 forecast model using data of twenty countries lead to the following results (see also Figure 1 and Figure 2):

The standard distribution of COVID-19 epidemics was estimated to be between 8.8 and 9.4 days, meaning that 99% of confirmed COVID-19 cases or deaths within a given region or country will occur between 45 and 48 days (Table 1, third last line). There are two exceptions to the standard distribution: the first COVID-19 wave in Korea was estimated to last 26.6 – 28.7 days and in Austria the duration of the COVID-19 wave was estimated to be between 34.4 and 38.1 days.

The time trends in number of deaths follows the trends in the number of confirmed infections and can be described by lag time, which differs between countries. This lag time was lowest (3.1 days) in Italy, Portugal, and Spain; medium (6.3 days) in Austria, Belgium, Brazil, Canada, China, Iran, Netherlands, UK, and USA; highest (9.5 days) in Czechia, Denmark, France, Germany, Japan, Korea, Sweden, and Switzerland.

To enhance comparisons of the timing of the estimated peaks in number of confirmed infections, we present these as number of day in 2020 (range 1 to 366; for example day 32 in 2020 is Feb 1). In China the first peak was estimated at day 40 (accounting for about 97% of total COVID-19 epidemic in China), and a small second peak at day 87 (accounting for 3% of total). The estimated total of the whole epidemic in China of 83 700 confirmed infections is close to the 83 005 confirmed infections reported by the WHO on April 6, 2020 for China. Also the estimated total of the whole epidemic in China of 3 367 deaths is close to the 3 340 reported deaths by the WHO. That is due to the fact that the model indicates that the COVID-19 epidemic in China is close to its end (at least regarding the current wave), and thus differences between model estimates and observed cases could only stem from misspecification of the model. The lower confidence interval of the model is with 72 789 confirmed infections about 10 000 cases lower than the observed numbers. This difference is due to the fact that the change in definition of how confirmed infections are counted is not accounted for in our model.

Besides China, there are five other countries with two peaks: Korea with a first peak at day 62 (74% of total) and a second peak at day 85 (26% of total); Japan with a first peak on day 67 (9% of total) and a second peak on day 102 (91% of total); Iran with a first peak on day 74 (25% of total) and a second peak on day 96 (75%); the peaks of the waves in Denmark and Sweden where assumed to be identical, with first peak on day 80 (20% of total in Denmark and 16% of total in Sweden), and a second peak on day 101.

For all other 14 countries only one peak could be observed according to the currently available data. Italy had its peak on day 85, Austria had its peak on day 87, Switzerland on day 89, Czechia, France, Germany, and Netherlands all on day 91, Spain on day 92, Belgium on day 94, Portugal on day 95, UK and Canada on day 98, Brazil and USA on day 99.

Among these 20 countries, it is predicted that the USA will reach the highest numbers (653 683 – 802 205) of confirmed infections and number of deaths (36 591 – 53 286).

Despite the fact that confidence intervals of our model are rather wide, we believe that our forecast can be helpful to inform decision makers. For example, for Switzerland the known cases on April 6, 2020 are 21 065 confirmed infections, and the model predicts a total between 24 240 and 27 498 confirmed infections; the observed number of deaths was 715, and the model forecasted between 1 225 and 2 044 deaths. Therefore, we predict that the majority of people who will get infected during this (first) epidemic wave are already infected.

If the model is estimated with the data provided by the Swiss cantons (www.corona-data.ch), using all cantonal data and accounting for days without new published data and setting the standard deviation of the normal distribution to 9, the estimated total number of confirmed COVID-19 infections is with 22 680 – 27 167 almost identical to the model using WHO data (see Figure 3 and Table 2 for Swiss cantons).

Methods

The model was estimated wit SAS 9.4M6 using PROC NLMIXED. The input variables are "date" for the date, an indicator variable named "dead" that is zero if "cases" indicate new confirmed infections, and one if "cases" indicate new number of deaths. We show the syntax here for China solely, as otherwise the syntax is quite extensive.

```
proc nlmixed data=whodata gconv=0 empirical qpoints=1;
parms tot_=85 m0=40 m1=80 p0=95 s=40 cd=-3 md=6;
tot = exp(log(tot_)+cd*dead);
IF first = 1 Then f = cdf('Normalmix',date,2,p0/100,(100-
p0)/100,mdy(12,31,2019)+m0+md*dead,mdy(12,31,2019)+m1+md*dead,s/5.16,s/5.16
);
Else              f = pdf('Normalmix',date-.5,2,p0/100,(100-
p0)/100,mdy(12,31,2019)+m0+md*dead,mdy(12,31,2019)+m1+md*dead,s/5.16,s/5.16
);
model cases ~ binomial(tot*1000,f+u);
random u ~ normal(0,0) subject=date;
predict tot*1000*f out=pred;
fs = cdf('Normalmix',date,2,p0/100,(100-
p0)/100,mdy(12,31,2019)+m0+md*dead,mdy(12,31,2019)+m1+md*dead,s/5.16,s/5.16
);
predict tot*1000*fs out=preds;
estimate "Peak of 1st. wave China (day of 2020)" m0;
estimate "Peak of 2nd. wave China (day of 2020)" m1;
estimate "Time between peaks China (days)" m1-m0;
estimate "Time lag of deaths vr. confirmed (days)" md;
estimate "Size of 1st. wave (%)" p0;
estimate "Total confirmed China" tot_*1000;
estimate "Total deaths China" exp(log(tot_)+cd)*1000;
estimate "Ratio deaths per confirmed China (%)" exp(cd)*100;
run;
```

Table 1: Derived estimates for the 20 countries

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Peak of 1st. wave China (day of 2020)	40.5137	0.4974	76	81.46	<.0001	0.05	39.5232	41.5043
Peak of 2nd. wave China (day of 2020)	87.1299	0.4732	76	184.13	<.0001	0.05	86.1874	88.0724
Time between peaks China (days)	46.6162	0.5762	76	80.91	<.0001	0.05	45.4686	47.7637
Size of 1st. wave China (%)	96.9532	0.2337	76	414.94	<.0001	0.05	96.4878	97.4186
Total confirmed China	83700	5473.61	76	15.29	<.0001	0.05	72798	94602
Total deaths China	3366.92	100.25	76	33.59	<.0001	0.05	3167.25	3566.59
Ratio deaths per confirmed China (%)	4.0226	0.3099	76	12.98	<.0001	0.05	3.4054	4.6399
Time lag of deaths vr. confirmed China (days)	6.3101	0.3906	76	16.15	<.0001	0.05	5.5322	7.0881
Peak of 1st. wave Korea (day of 2020)	61.6431	0.09430	76	653.67	<.0001	0.05	61.4552	61.8309
Peak of 2nd. wave Korea (day of 2020)	85.4521	0.4740	76	180.28	<.0001	0.05	84.5081	86.3962
Time between peaks Korea (days)	23.8091	0.4495	76	52.96	<.0001	0.05	22.9137	24.7044
Size of 1st. wave Korea (%)	73.9857	0.8099	76	91.36	<.0001	0.05	72.3727	75.5986
Total confirmed Korea	10564	159.01	76	66.44	<.0001	0.05	10248	10881
Total deaths Korea	206.46	29.7374	76	6.94	<.0001	0.05	147.24	265.69
Ratio deaths per confirmed Korea (%)	1.9544	0.2856	76	6.84	<.0001	0.05	1.3855	2.5233
Time lag of deaths vr. confirmed Korea (days)	9.5248	0.6973	76	13.66	<.0001	0.05	8.1360	10.9136
Peak of 1st. wave Japan (day of 2020)	67.1781	1.9100	76	35.17	<.0001	0.05	63.3740	70.9821
Peak of 2nd. wave Japan (day of 2020)	101.66	1.6834	76	60.39	<.0001	0.05	98.3085	105.01
Time between peaks Japan (days)	34.4833	1.1954	76	28.85	<.0001	0.05	32.1024	36.8641
Size of 1st. wave Japan (%)	9.4846	1.5759	76	6.02	<.0001	0.05	6.3460	12.6232
Total confirmed Japan	9890.41	1883.39	76	5.25	<.0001	0.05	6139.33	13641
Total deaths Japan	496.61	129.17	76	3.84	0.0002	0.05	239.34	753.88
Ratio deaths per confirmed Japan (%)	5.0211	0.6177	76	8.13	<.0001	0.05	3.7909	6.2513

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Label	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Time lag of deaths vr. confirmed Japan (days)	9.5248	0.6973	76	13.66	<.0001	0.05	8.1360	10.9136
Peak of 1st. wave Iran (day of 2020)	74.4012	1.1258	76	66.09	<.0001	0.05	72.1590	76.6434
Peak of 2nd. wave Iran (day of 2020)	95.9140	0.8768	76	109.39	<.0001	0.05	94.1677	97.6603
Time between peaks Iran (days)	21.5128	1.0362	76	20.76	<.0001	0.05	19.4491	23.5765
Size of 1st. wave Iran (%)	24.8075	1.5933	76	15.57	<.0001	0.05	21.6342	27.9807
Total confirmed Iran	88479	4152.15	76	21.31	<.0001	0.05	80209	96749
Total deaths Iran	7974.96	928.15	76	8.59	<.0001	0.05	6126.39	9823.53
Ratio deaths per confirmed Iran (%)	9.0134	0.7543	76	11.95	<.0001	0.05	7.5110	10.5158
Time lag of deaths vr. confirmed Iran (days)	6.3101	0.3906	76	16.15	<.0001	0.05	5.5322	7.0881
Peak of wave Italy (day of 2020)	85.0982	0.3970	76	214.34	<.0001	0.05	84.3075	85.8890
Total confirmed Italy	142275	4579.09	76	31.07	<.0001	0.05	133155	151395
Total deaths Italy	19054	394.51	76	48.30	<.0001	0.05	18268	19840
Ratio deaths per confirmed Italy (%)	13.3923	0.2607	76	51.37	<.0001	0.05	12.8731	13.9115
Time lag of deaths vr. confirmed Italy (days)	3.1250	0.2408	76	12.98	<.0001	0.05	2.6453	3.6046
Peak of 1st. wave Denmark (day of 2020)	79.7005	1.3762	76	57.91	<.0001	0.05	76.9595	82.4415
Peak of 2nd. wave Denmark (day of 2020)	100.50	1.2904	76	77.89	<.0001	0.05	97.9341	103.07
Time between peaks Denmark (days)	20.8037	1.2571	76	16.55	<.0001	0.05	18.3000	23.3075
Size of 1st. wave Denmark (%)	20.0012	4.2176	76	4.74	<.0001	0.05	11.6010	28.4013
Total confirmed Denmark	9218.81	992.00	76	9.29	<.0001	0.05	7243.07	11195
Total deaths Denmark	810.67	199.40	76	4.07	0.0001	0.05	413.53	1207.81
Ratio deaths per confirmed Denmark (%)	8.7937	1.5637	76	5.62	<.0001	0.05	5.6793	11.9080
Time lag of deaths vr. confirmed Denmark (days)	9.5248	0.6973	76	13.66	<.0001	0.05	8.1360	10.9136
Peak of wave Switzerland (day of 2020)	88.8916	0.3520	76	252.50	<.0001	0.05	88.1905	89.5928

Table 1: Derived estimates for the 20 countries

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Total confirmed Switzerland	25869	817.89	76	31.63	<.0001	0.05	24240	27498
Total deaths Switzerland	1634.47	205.52	76	7.95	<.0001	0.05	1225.14	2043.80
Ratio deaths per confirmed Switzerland (%)	6.3183	0.6732	76	9.39	<.0001	0.05	4.9775	7.6592
Time lag of deaths vr. confirmed Switzerland (days)	9.5248	0.6973	76	13.66	<.0001	0.05	8.1360	10.9136
Peak of wave Austria (day of 2020)	86.5209	0.1816	76	476.51	<.0001	0.05	86.1592	86.8825
Total confirmed Austria	12860	256.90	76	50.06	<.0001	0.05	12349	13372
Total deaths Austria	281.84	10.2544	76	27.48	<.0001	0.05	261.41	302.26
Ratio deaths per confirmed Austria (%)	2.1916	0.08491	76	25.81	<.0001	0.05	2.0225	2.3607
Time lag of deaths vr. confirmed Austria (days)	6.3101	0.3906	76	16.15	<.0001	0.05	5.5322	7.0881
Peak of 1st. wave Sweden (day of 2020)	79.7005	1.3762	76	57.91	<.0001	0.05	76.9595	82.4415
Peak of 2nd. wave Sweden (day of 2020)	100.50	1.2904	76	77.89	<.0001	0.05	97.9341	103.07
Time between peaks Sweden (days)	20.8037	1.2571	76	16.55	<.0001	0.05	18.3000	23.3075
Size of 1st. wave Sweden (%)	16.0229	2.5612	76	6.26	<.0001	0.05	10.9219	21.1239
Total confirmed Sweden	15201	2052.30	76	7.41	<.0001	0.05	11113	19288
Total deaths Sweden	2092.39	529.98	76	3.95	0.0002	0.05	1036.85	3147.92
Ratio deaths per confirmed Sweden (%)	13.7653	2.1831	76	6.31	<.0001	0.05	9.4171	18.1134
Time lag of deaths vr. confirmed Sweden (days)	9.5248	0.6973	76	13.66	<.0001	0.05	8.1360	10.9136
Peak of wave Germany (day of 2020)	91.2758	0.3769	76	242.16	<.0001	0.05	90.5251	92.0265
Total confirmed Germany	129593	3620.72	76	35.79	<.0001	0.05	122382	136805
Total deaths Germany	4248.38	511.64	76	8.30	<.0001	0.05	3229.36	5267.41
Ratio deaths per confirmed Germany (%)	3.2782	0.3558	76	9.21	<.0001	0.05	2.5697	3.9868
Peak of wave France (day of 2020)	91.0830	0.3683	76	247.28	<.0001	0.05	90.3494	91.8166
Total confirmed France	93709	3519.89	76	26.62	<.0001	0.05	86698	100719
Total deaths France	23379	3724.26	76	6.28	<.0001	0.05	15962	30797

Table 1: Derived estimates for the 20 countries

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Ratio deaths per confirmed France (%)	24.9489	3.4918	76	7.15	<.0001	0.05	17.9945	31.9034
Peak of wave Spain (day of 2020)	91.6253	0.2396	76	382.37	<.0001	0.05	91.1481	92.1026
Total confirmed Spain	180790	3544.84	76	51.00	<.0001	0.05	173730	187850
Total deaths Spain	20770	868.45	76	23.92	<.0001	0.05	19041	22500
Ratio deaths per confirmed Spain (%)	11.4887	0.3682	76	31.20	<.0001	0.05	10.7554	12.2220
Peak of wave Netherlands (day of 2020)	91.4433	0.3503	76	261.04	<.0001	0.05	90.7456	92.1410
Total confirmed Netherlands	24449	801.38	76	30.51	<.0001	0.05	22853	26045
Total deaths Netherlands	3781.55	182.75	76	20.69	<.0001	0.05	3417.58	4145.52
Ratio deaths per confirmed Netherlands (%)	15.4669	0.8794	76	17.59	<.0001	0.05	13.7154	17.2183
Peak of wave Czechia (day of 2020)	91.0802	0.3636	76	250.52	<.0001	0.05	90.3561	91.8043
Total confirmed Czechia	6172.80	221.94	76	27.81	<.0001	0.05	5730.77	6614.82
Total deaths Czechia	193.92	26.2781	76	7.38	<.0001	0.05	141.58	246.26
Ratio deaths per confirmed Czechia (%)	3.1415	0.3674	76	8.55	<.0001	0.05	2.4098	3.8733
Peak of wave Belgium (day of 2020)	94.1727	0.4382	76	214.92	<.0001	0.05	93.3000	95.0454
Total confirmed Belgium	31644	1166.44	76	27.13	<.0001	0.05	29321	33967
Total deaths Belgium	4133.11	291.94	76	14.16	<.0001	0.05	3551.66	4714.56
Ratio deaths per confirmed Belgium (%)	13.0612	0.9160	76	14.26	<.0001	0.05	11.2369	14.8855
Peak of wave Portugal (day of 2020)	94.8623	0.4362	76	217.45	<.0001	0.05	93.9935	95.7312
Total confirmed Portugal	19012	660.44	76	28.79	<.0001	0.05	17697	20327
Total deaths Portugal	646.27	37.0682	76	17.43	<.0001	0.05	572.44	720.09
Ratio deaths per confirmed Portugal (%)	3.3992	0.1005	76	33.81	<.0001	0.05	3.1990	3.5995
Peak of wave UK (day of 2020)	97.6017	0.6054	76	161.21	<.0001	0.05	96.3958	98.8075
Total confirmed UK	100992	6814.55	76	14.82	<.0001	0.05	87420	114565
Total deaths UK	22149	2006.92	76	11.04	<.0001	0.05	18152	26146
Ratio deaths per confirmed UK (%)	21.9312	1.5390	76	14.25	<.0001	0.05	18.8660	24.9965

Table 1: Derived estimates for the 20 countries

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Peak of wave Brazil (day of 2020)	98.9297	0.8591	76	115.15	<.0001	0.05	97.2186	100.64
Total confirmed Brazil	24739	2367.54	76	10.45	<.0001	0.05	20023	29454
Total deaths Brazil	2378.02	307.72	76	7.73	<.0001	0.05	1765.14	2990.89
Ratio deaths per confirmed Brazil (%)	9.6126	0.7593	76	12.66	<.0001	0.05	8.1002	11.1250
Peak of wave USA (day of 2020)	98.7798	0.5368	76	184.02	<.0001	0.05	97.7107	99.8490
Total confirmed USA	727944	37286	76	19.52	<.0001	0.05	653683	802205
Total deaths USA	44939	4191.08	76	10.72	<.0001	0.05	36591	53286
Ratio deaths per confirmed USA (%)	6.1734	0.4051	76	15.24	<.0001	0.05	5.3665	6.9802
Peak of wave Canada (day of 2020)	97.7030	0.6031	76	161.99	<.0001	0.05	96.5017	98.9042
Total confirmed Canada	29651	1905.84	76	15.56	<.0001	0.05	25855	33447
Total deaths Canada	1052.24	140.90	76	7.47	<.0001	0.05	771.61	1332.87
Ratio deaths per confirmed Canada (%)	3.5487	0.2969	76	11.95	<.0001	0.05	2.9573	4.1401
Duration of COVID-19 wave (99%) in days	46.7877	0.7668	76	61.02	<.0001	0.05	45.2605	48.3150
Duration of first COVID-19 wave (99%) in Korea in days	27.6039	0.5267	76	52.41	<.0001	0.05	26.5550	28.6529
Duration of COVID-19 wave (99%) in Austria in days	36.2422	0.9112	76	39.78	<.0001	0.05	34.4275	38.0569

Figure 1: Observed (red line) and predicted number of confirmed COVID-19 infection in 20 countries, using data from April 6, 2020

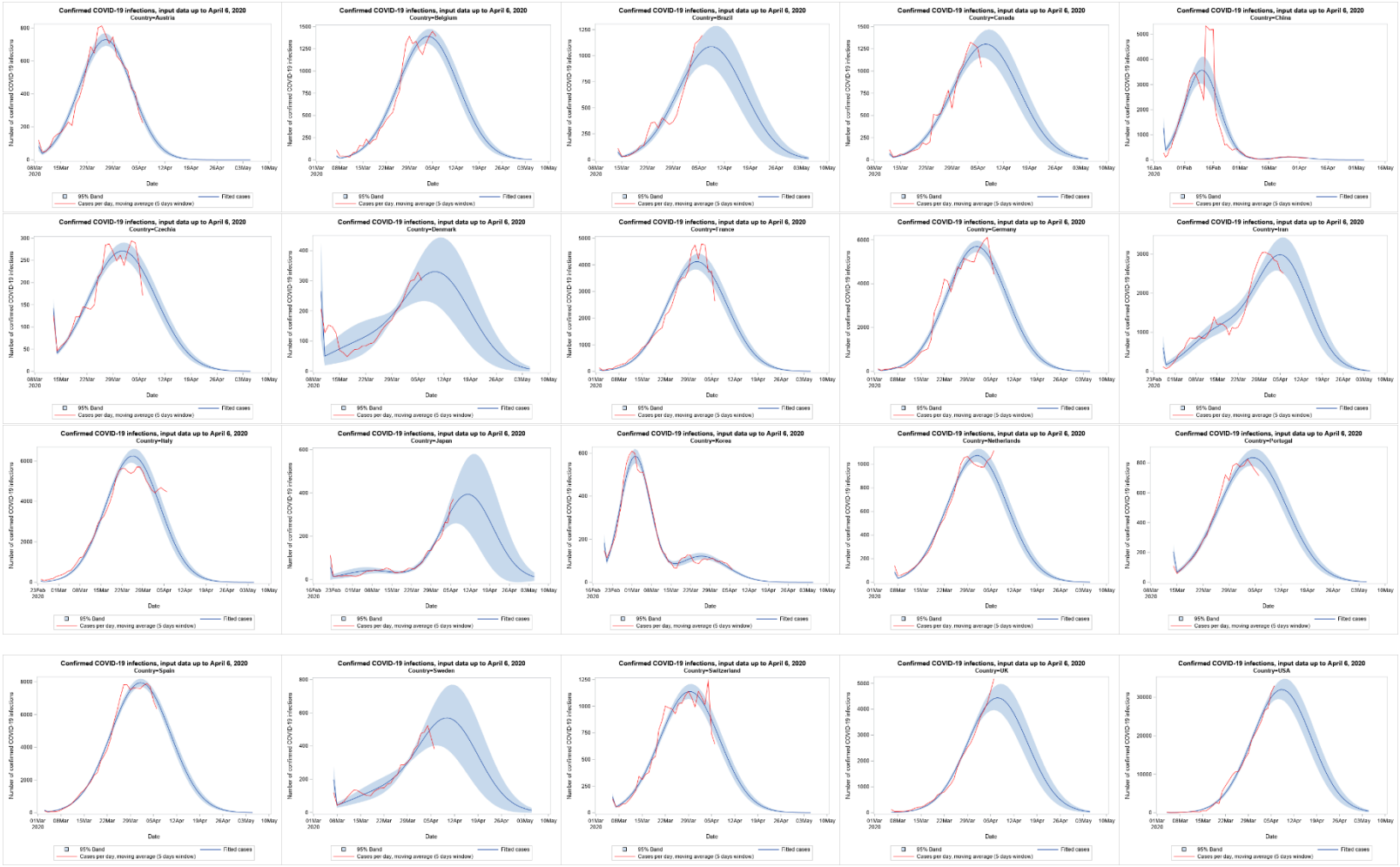

Figure 2: Observed (red line) and predicted number of COVID-19 deaths in 20 countries, using data from April 6, 2020

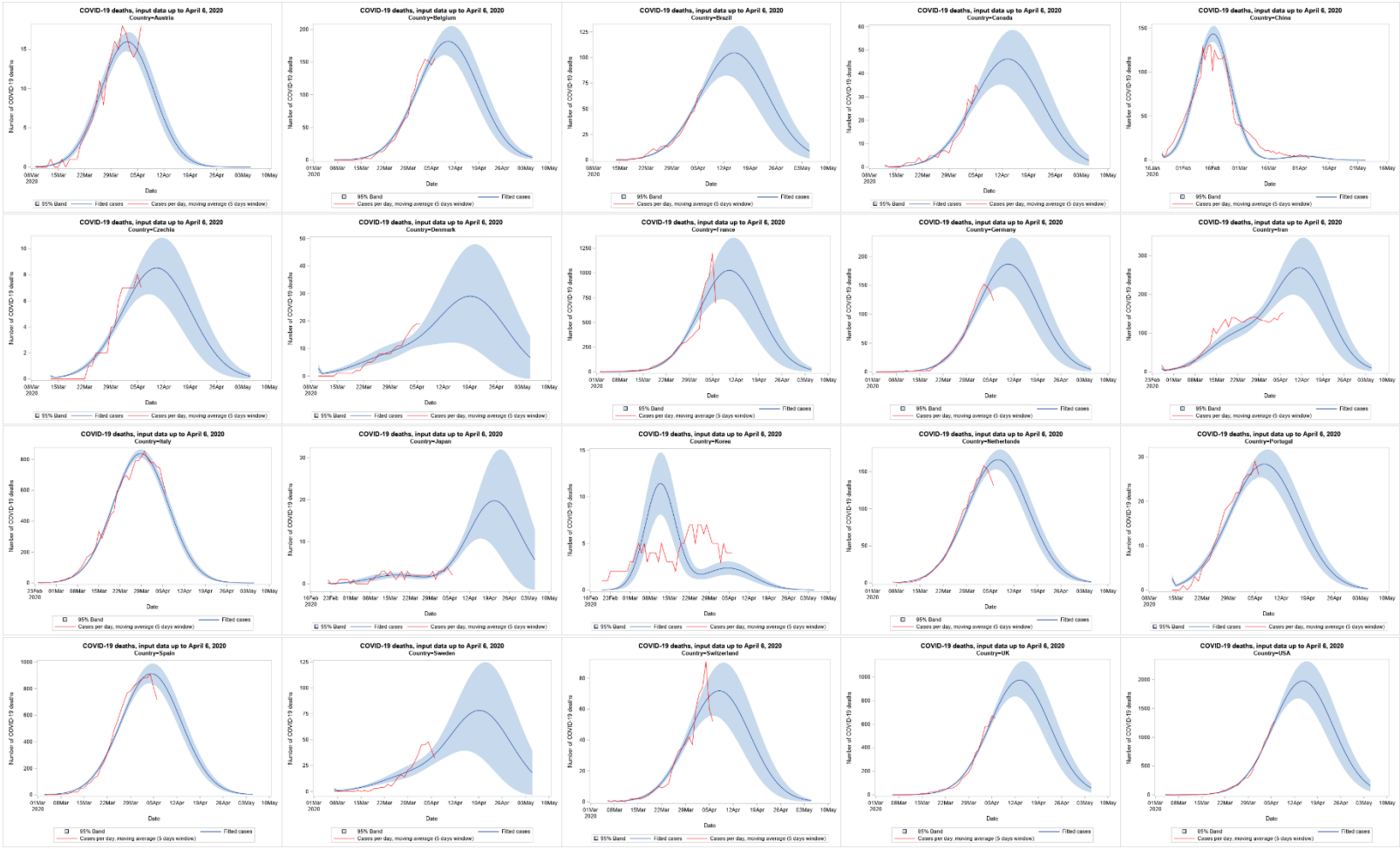

Figure 3: Observed and model fitted cumulative number of confirmed COVID-19 infection in the 26 cantons of Switzerland, using data from April 6, 2020

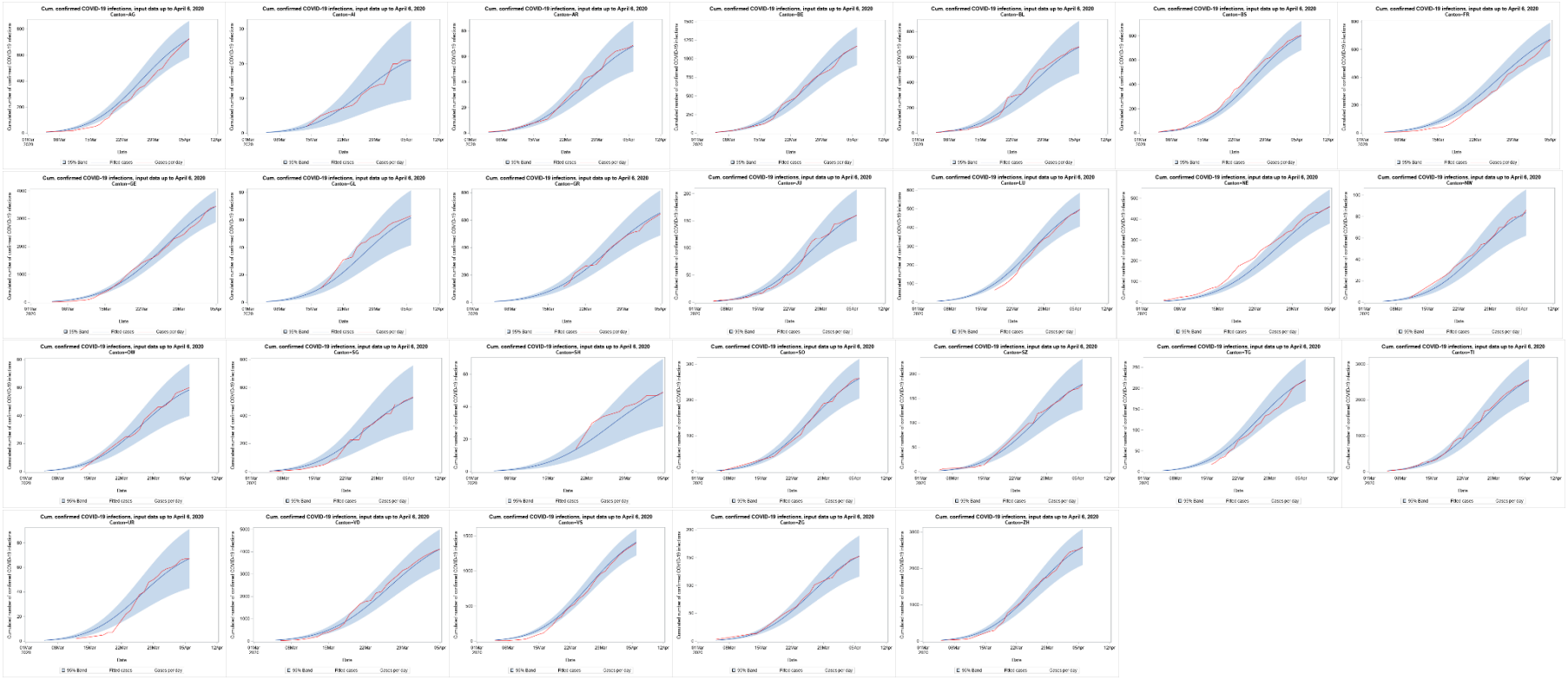

Table 2: Observed and predicted total number of confirmed COVID-19 infection in the 26 cantons of Switzerland, using data from April 6, 2020

	AG	AI	AR	BE	BL	BS	FR	GE	GL	GR	JU	LU	NE	NW	OW	SG	SH	SO	SZ	TG	TI	UR	VD	VS	ZG	ZH	CH
Observed until April 6, 2020	727	21	69	1173	682	803	669	3439	63	646	160	497	459	86	60	532	49	261	178	219	2546	67	4115	1400	152	2590	21663
Predicted total	819	24	77	1329	770	911	786	4023	70	763	182	563	537	95	66	600	57	295	203	250	2895	76	4811	1600	173	2948	24923
95% lower	662	10	54	1042	536	773	646	3342	47	572	128	455	444	70	44	337	32	231	143	191	2230	48	3826	1389	130	2388	22680
95% upper	977	37	100	1617	1005	1049	925	4703	93	954	236	671	631	120	88	862	82	358	264	309	3560	104	5796	1812	216	3507	27166