北京大学 PEKING UNIVERSITY

Time: 3 p.m. (Beijing Time), April 3, 2020

Five-Day Report on International Epidemic Situation of COVID-19

Pandemic continues: US persists as Italy levels off

Data: Based on the outbreak data up to 8 p.m. (Beijing Time), April 2, 2020

24 Countries concerned: (1) Asia: Iran, South Korea, Japan (excluding Diamond Princess), Malaysia, Singapore and Thailand; (2) Europe: Italy, Spain, France, Germany, UK, Holland, Switzerland, Belgium, Austria, Denmark, Norway, Sweden, Turkey (newly added), and Portugal (newly added); (3) North America: US and Canada; (4)Other: Brazil (newly added), and Australia (newly added).

Abstract: The epidemic situation in the United States has continually deteriorated, exhibiting a trend of exponential growth. While Italy's trend levels off, remaining European countries continue to show exponential growth and high mortality rates. The Korean epidemic has improved overall, but Japan had experienced a rebound in its epidemic situation. As the mandatory abilities of European and American governments are more limited than that of the Chinese government, the pandemic situation is at high risk of further worsening. If countries do not adopt harsh measures on blocking pathways of infection, 95% prediction interval for the average final number of total infections is between 5.5 millions-11.78 millions in these 24 countries. The lower limit decreases by 4.5 millions comparing to the previous report on March 29th. The upper limit is calculated excluding the Brazil's upper limit of 119 millions (Brazil epidemic has just started, exhibiting great uncertainty). We predict that the pandemic in the 24 countries will continue to late 2020 or even early 2021 (similar to the previous report, usually with about a week advance). The overall infection rate in the 24 countries will increase from 0.053% on April 2 to 0.38%-0.77%. The epidemic situations are in particularly concerning in developing nations with high percentage of low-income population and high density housing, such as Brazil. The long duration of overseas

epidemic situations will bring huge impacts and challenges on World's and China's economy and international security.

Method: Apply the vSEIR model developed by our team to calculate the effective reproduction number R for each country. See a medRxiv posting for an early version based on vSIR model and applications on China province's epidemic analysis: https://www.medrxiv.org/content/10.1101/2020.02.17.20024257v1

Special terms: the effective reproduction number (R) is the average number of infections made by an infected while being infectious. Only when R is less than 1, the outbreak begins to slow down and gradually comes to an end. R is the most determining factor for the internal dynamics of an outbreak. Our early study on COVID-19 in 30 provinces of China shows that R is an effective leading index and has good forecasting power for the COVID-19 outbreak in China under the vSIR model framework.

Results: (i) The effective reproduction number R at 10.5 and 14 days infectious duration (Figure1)， the infection loading statistics in the past 7 days, projected number of overall cases and new cases in next seven days (new), and risk rating for each country (Table 1). (ii) Plots of the cumulative cases and infection rate for each country(Figure 2). (iii) Time series plots of the 14-day R of international areas along with Hubei and Beijing in China to gain information on the epidemic stages (Figure 3-1 and 3-2).

Key Findings: (i) North America: The 14-day R value in the United States (hereinafter referred to as the 14-day R value) reached a peak of 17.5 on March 17, decreased to 6.45 on March 29 and is currently down to 3.7. A decreasing trend is shown, but the current value remains high. We estimate a total of 133k undocumented cases are currently undiagnosed. The U.S. outbreak will continue to deteriorate exponentially because R value is as high as 6.45 and the infection base remains large. Based on the current reproductive power and removal rate, the U.S. epidemic is expected to end between November and December of 2020, with the number of infected reach 1.5 to 2.38 millions. The risk rating of the U.S. is F.

(ii) Europe: The Italy's trend levels off with the R value falls below 1 for the first time. Remaining European countries still in the stage of exponential growth, exhibiting similar patterns of epidemic infection to Italy, but with a one-week time lag. The average R value decreased from 3.39 in the 12 countries five days ago to current average of 2.32 in the 14 countries, with a total of 371,600 confirmed cases. At present, the highest R of 5.09 appears in Turkey (15.1k currently infected cases), followed by the UK 4.09 (27k infections), France 3.3 (42k infections), and Sweden 2.87 (4.7k infections). Based on current data and calculations, we estimate that there are currently

176,600 undiagnosed cases in the 14 European countries, accounting for 47.5% of currently infected cases. New cases are expecting to reach 300k in the next seven days. We also expect that the epidemic in Italy will end in September of 2020 (that is, all infected cases are cleared), with the total confirmed cases eventually reaching 200,000. Spain is expected to end the epidemic by October 2020, with about 250,000 confirmed cases. The epidemic situation in three Nordic countries (Sweden, Norway, and Denmark) may results in underestimation due to their under-testing policy. We may remove these three countries from our analysis should these three countries continue to practice such policy.

(iii) Asia: Japan's R-value has rebounded to 2.91, casting much uncertainty with the future course of the epidemic. If the epidemic situation has not been controlled, it is possible that the total infected cases may exceed 10 millions. South Korea's R-value has fallen below 1 for 24 consecutive days, and the inflection point of the epidemic was confirmed on March 24, making South Korea the only country in the 24 countries who has a declining epidemic. Iran's R value has fallen from 3.13 to 2.06 (31k infections). The epidemic situation is still severe. The epidemic situations in Singapore, Malaysia, and Thailand are still in stalemates, with the R value still greater than 1, and the epidemics have not been controlled. Among them, there are more than 2k cases in Malaysia and more than 1k in Thailand, both of which deserve China's vigilance.

Other Findings:

1. The 14-day R value in the United States dropped from 6.45 on March 29 to 3.7. A total of 217k people are diagnosed, among them are 203k active cases, with more than 20k new cases on a single day for the third consecutive day. The estimated number of undocumented cases exceeded 130k. It is estimated that there will be more than 200k new cases in the coming week, and the number of cumulative infections will reach over 400k at that time. It is expected that the epidemic will end by the end of 2020, with about 1.5 to 2.38 million cumulative cases. Compared with the 1 to 2.56 millions range forecast 5 days ago, the lower limit has increased significantly. The epidemic in the United States has continued to spread, with the highest F risk rating. The cumulative number of confirmed cases in New York State has exceeded 80k, and 27 states and overseas territories have entered a state of a major disaster. Canada's R value has dropped from 5.21 to 3.76, with more than 10k cumulative infections, over 8k active cases and 1k increase in a single day. The epidemic is in a stage of rapid development, with a risk rating of D. It is expected that there will be more than 7k new cases in the next seven days.

2. The R value of Italy in the 14-day period was 0.89, which fell below 1 for the first time, and the epidemic has eased, but it was not significantly less than 1 at the 5% level. A total of 110.6k people were diagnosed, with 80.6k existing cases. The mortality rate climbed to 16.96%, and the cure rate was 25.5%. It is estimated that the potential cases are 20k, and there will be about 30k new cases in the next 7 days. The epidemic is expected to end in September 2020, with a total of nearly 200k cumulative infected cases then. The risk rating is still the highest F. The R value in Italy has fallen rapidly from over 30 to 0.89 on April 2 since the end of February, which is similar to that of Hubei Province in mid-February. The epidemic is concentrated in the northern region, with more than 25k active cases and more than 7.5k deaths in Lombardy; for Emilia-Romagna, there are more than 10k active cases and more than 1.5k deaths.

3. The rate of deterioration of the Spanish epidemic has slowed down. The R value has dropped from 3.86 to 2.08, with the cumulative cases exceeding 100k. It is estimated that there are still more than 40k undocumented cases, and about 60k new cases will be diagnosed in the next 7 days, 20k fewer than the forecast 5 days ago. It is expected that the epidemic will end in November 2020, and the total number of confirmed cases will reach 250k, which will be halved compared to last forecast (the final number of infections reached over 500k). The risk rating is still the highest F. The mortality rate climbed to 8.86% and the cure rate rose to 14.4%. Spain will overtake Italy in the next few days as the country with the worst epidemic in Europe.

4. The epidemic is stuck in France and Germany. The R values are 3.3 and 1.92 respectively, similar to that of Hubei in mid-February, with a risk rating of E. For France, the R value remained unchanged at around 3.5 from March 26 to April 2. The number of cumulative cases exceeded 50k, the cure rate rose to 18.2%, the mortality rate rose to 6.76%, and another 29.5k undocumented cases are estimated. In the next 7 days, there will be about 55k new cases. It is estimated that the final number of infected people will reach more than 1 to 3 millions, which is narrower than the previous forecast. Germany's R-value rebounded from more than 3.5 a week ago to 1.92 on April 2. The existing cases exceeded 60k, and it is estimated that there are another 27.3k potential cases. The cure rate drops from more than 14% to 12.59%, and the mortality rate is 1.08%. It is estimated that there will be 45k new cases in the next 7 days. It is expected that the epidemic will end in October 2020, and the total number of infected people will be around 150k.

5. Britain ’s 14-day R value reduced to 4.09. As of April 2, there were 27k active cases in the UK, with nearly 3k new cases in a single day. The estimated number of undocumented cases is 19.4k, and it is estimated that about 40k new cases will be added in the next 7 days. The mortality rate is 5.2%. It is expected that the UK epidemic will continue until the end of October to November 2020, and the total number of infections will eventually be 140k to 270k, which is narrower than the previous forecast.

6. Iran ’s 14-day R value fell to 2.06, with a risk rating of E. There are 30.6k active cases and a total of 3.16k deaths. It is estimated that the number of cumulative infections by the end of the epidemic will be between 80k and 100k, significantly fewer than last forecast.

7. South Korea ’s 14-day R value is 0.3, which has been below 1 for 24 consecutive days, with the risk rating downgraded to C. The epidemic has reached its inflection point on March 24. The number of active cases is declining, with 4,240 current infections. South Korea is expected to witness the end of epidemic in July to September 2020, and the total number of infections will reach 10k.

8. Japan ’s 14-day R value rebounded to 2.91, with 2,051 active cases. It is expected that about 2,911 to 3,319 new cases will be added in the coming week. Due to the recent rebound, the development of the epidemic is still uncertain. The number of total confirmed cases may be over 20k by the end of the epidemic. If measures are not taken in a timely manner, there will be more infections, and the risk rating is upgraded from C to D. The Tokyo Olympics has been confirmed to be postponed to July 2021.

9. Malaysia's 14-day R value fell to 1.22, still significantly greater than 1, and the epidemic is not effectively controlled. Singapore's R value has recently dropped to 1.41, with more than 1k infected cases. In addition, the proportion of infectious cases within the territory increased, so Singapore is faced with both the risk of transmission of clustered cases within the country and a high risk of imports abroad. Thailand's 14-day R value fell to 1.39, with a risk rating of C.

10. Australia has an R value of 1.11, with a risk rating of C. There are 4,572 active cases, 5,116 cumulative cases, and about 1.3k undocumented cases. It is estimated that there will be 2k new cases in the next 7 days. It is expected that the epidemic will end in August 2020, with a cumulative infection of nearly 10k people.

The above analysis is just for reference. We will update the international epidemic situation and report in time.

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See also www.songxichen.com for more on the COVID-19 project.

Table 1. Effective Reproduction Number (R) on April 2, 2020, the numbers of infectious, imputed undiagnosed, and other counting statistics in 1000 and prediction for the next seven day's new infection, the ending time and final size of the epidemics in 1000. The R is based 14 days infection duration and ++ (--) indicates that R is greater (less) than 1 at the 5% statistical significance and [x] represents the number of consecutive days for which R has been significantly less than 1 at 5%. Numbers or Letters inside () are the previous day value. The risk level of the epidemic in each region is derived from the value of R and the dynamics of infections, ordering from A to F with increasing severity.

Rank	Country	R	Active Cases on March 28	Undiagnosed Cases (in k)	New Cases in Past 7 Days (in k)	Projected New Cases in Next 7 Days (in k)	Projected Ending Time	Projected Final Size (in k)	Risk Level
1	US	3.7++(6.4)	203(178)	133.3	147.5	207.8 – 235.6	20/11/20 - 20/12/22	1,527.2 – 2,383.5	F
2	Spain	2.08++(3.8)	78(78)	41.6	54.1	73.9 - 75.9	20/10/29 - 20/11/16	343.2 - 394	F
3	Italy	0.89(1.7)	81(78)	20.6	36.2	30 – 30.9	20/9/9 - 20/10/7	143.9 - 184.6	F
4	UK	4.09++(6.4)	27(23)	19.4	19.9	43.3 – 47.3	20/10/2 - 20/11/25	173.5 – 415.1	E
5	France	3.3++(3.8)	42(39)	29.5	31.8	65.8 - 69	21/5/31 - 21/9/29	1,306.2 – 3,855	E
6	Iran	2.06++(3.1)	31(29)	14.3	21.1	25.6 – 26.9	20/8/31 - 20/9/1	81.9 – 84.3	E
7	Germany	1.92++(3)	64(58)	27.3	35.4	55.3 – 57.2	20/10/2 - 20/10/12	209.9 - 240	E
8	Turkey	5.19++	15(13)	11.6	13.2	21 – 24.4	20/10/26 - 20/11/5	84 – 98.8	D
9	Brazil	4.95++	7(6)	5.9	4.4	18.3 – 22.1	20/11/25 - 22/10/28	255.7 – 119,190.2	D
10	Canada	3.76++(5.2)	8(7)	6	6.3	7.2 – 10	20/11/25 - 21/7/16	132.2 - 1,614.4	D
11	Sweden*	2.87++(1.9)	5(4)	3.1	2.4	6.4 – 7.4	21/1/18 - 21/8/9	1,056.3 – 7,116.3	D
12	Portugal	2.86	8(7)	4.6	5.3	5.4 - 6	20/8/16 - 20/8/20	16.7 – 18.8	D
13	Belgium	2.35(6.2)	12(11)	6.4	9.1	10.9 - 11.5	20/8/22 - 20/8/24	30.6 – 32.3	D

14	Holland	2.07++(2.9)	9.5(8.6)	4.5	6.2	6.2 – 6.8	20/10/10 - 20/12/1	39.1 – 59.8	D
15	Denmark*	1.81++(1.5)	2.1(2.7)	1.2	1.4	2.6 – 2.9	21/1/10 - 22/6/5	106.4 – 2,837.6	D
16	Austria	1.12(4.6)	8.9(8.7)	2.8	4.9	1.9 – 2.9	20/8/10 - 20/9/12	13.5 – 21.9	D
17	Switzerland*	1.03(1.6)	15(14)	3	7.4	4.7 – 5.2	20/8/21 - 20/9/1	25.7 - 30.6	D
18	Norway*	0.85(2.3)	4.8(4.6)	1	1.8	0.9 - 1	20/7/31 - 20/8/2	6.3 – 6.7	D
19	South Korea	0.3--[24](0.2)	4.2(4.3)	0.5	0.7	0.7 - 0.7	20/9/4 - 20/9/24	12.1 – 12.3	D
20	Japan	2.91++(1.2)	2.1(1.7)	1.2	1.1	2.9 – 3.3	20/7/27 - 22/11/29	4.8 – 83,048.4	D(C)
21	Singapore	1.41++(1.5)	0.8(0.7)	0.3	0.3	0.5 - 0.6	20/7/26 - 20/10/28	2.1 – 4.7	C
22	Thailand	1.39++(2.2)	1.4(0.7)	0.6	0.8	1 - 1.1	20/8/7 - 20/9/17	4 – 5.7	C
23	Malaysia	1.22++(1.6)	2.3(2.2)	0.8	1.1	1.3 – 1.5	20/8/16 - NA	6.5 – 5,858.9	C
24	Australia	1.11	5.0(4.7)	1.3	2.3	1.5 – 2.2	20/8/2 - 20/8/23	7.2 – 10.8	C

Note 1: The turning point of an outbreak: Due to the random fluctuations and reporting errors in the data, we suggest that the turning point of an outbreak in a region is confirmed only when the timespan for which R has been significantly lower than 1 is equal to or larger than the average duration from the infection date to the clinical confirmation date (we suggest using 7 days based on Chinese data for COVID-19). That is, if the R based on the 14-day infectious duration has been significantly (at 5% level) lower than 1 for 7 consecutive days, it may be declared that the turning point has been reached.

Note 2: Sweden, Denmark, and Norway began to narrow the scope of detection to critically ill patients and high-risk groups (doctors, elderly, etc.) in early March. The epidemic may be underestimated.

Note 3: The reason why the 95% predicted interval for the final cumulative confirmed cases in France, Canada, Austria, Denmark, Sweden, and Norway is very wide is that the R value has not fallen recently.

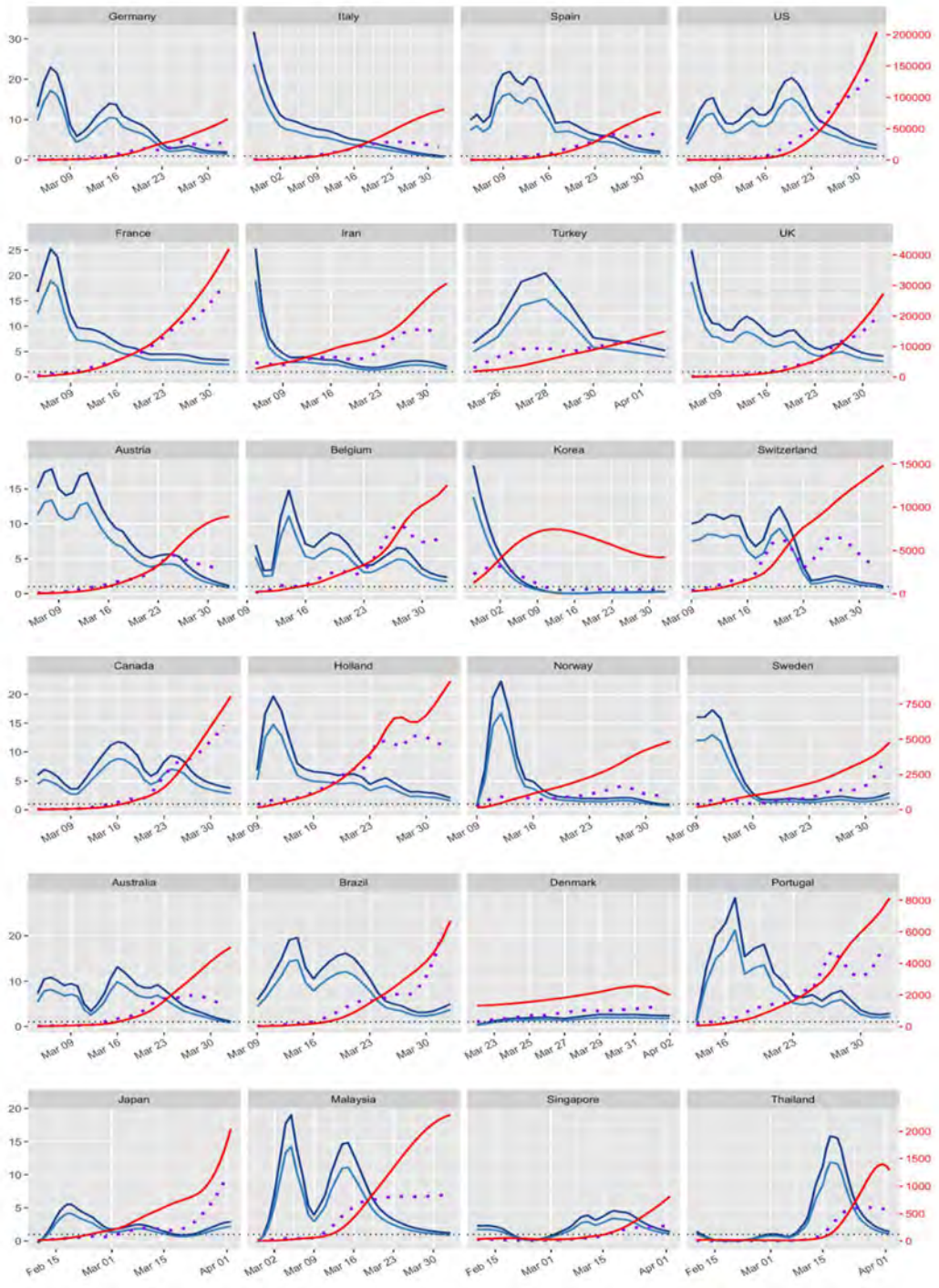

Figure 1. Time series plots of infected cases and estimated effective reproduction numbers R, the logarithm of infected cases (red) and the estimated logarithm of infected but undocumented cases (purple) up to April 2, 2020. Two Rs are given based on 10.5-day infectious duration (blue) and 14-day duration (navy blue). The critical threshold level R=1 is the horizontal dashed line.

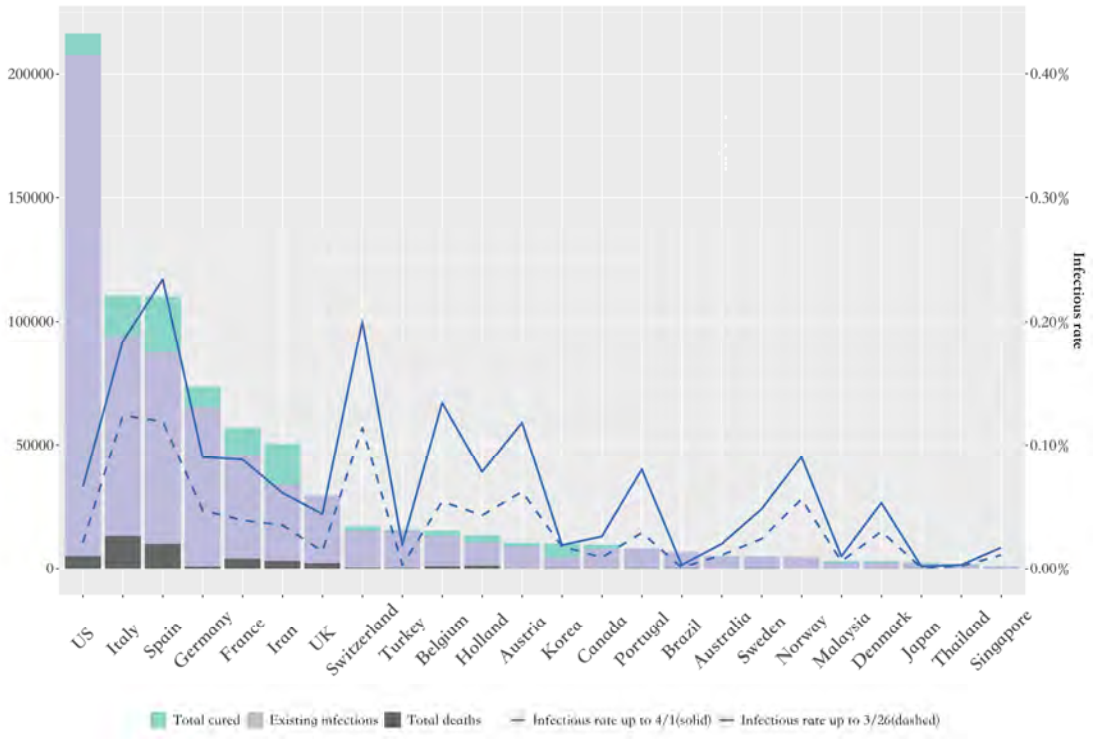

Figure 2. The cumulative number of cases and population infection rates in April 2, 2020 in each country. Green: cumulative number of people cured; purple: number of existing infections; gray: cumulative number of deaths; solid blue line: population infection rate; blue dotted line: population infection rate 7 days ago.

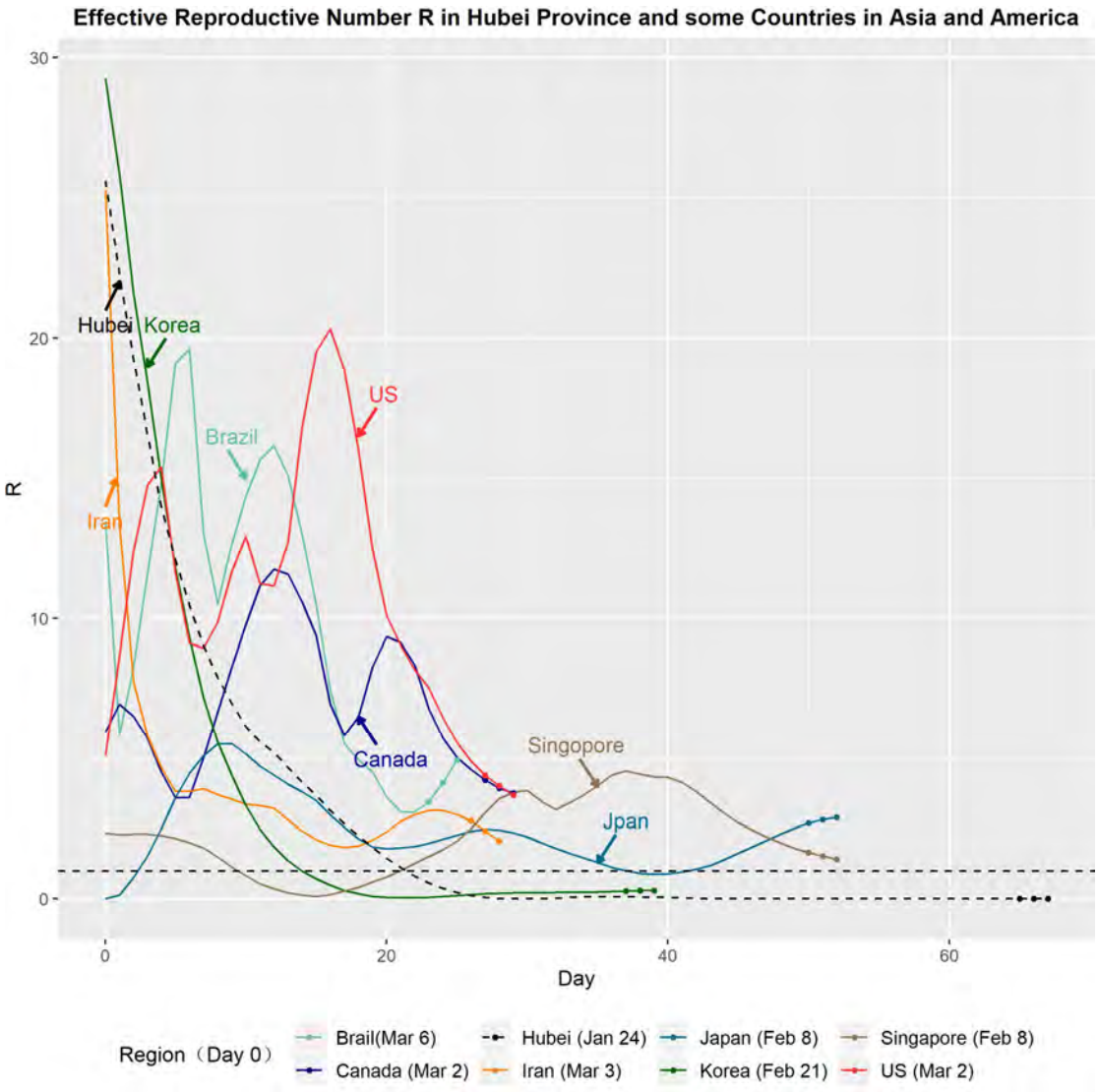

Figure 3.1. Effective Reproduction Number (R) in Canada, Iran, US, Korea, Japan, Singapore and Hubei Province in China up to April 2, 2020, based on a 14-day Infectious Duration. Day 0 is the fifth day since the outbreak as given in the legend. Points at the end of the line refer to the value of R of recent 3 days. The critical threshold R=1 is marked by the horizontal dashed line. Only when R is less than 1, the outbreak begins to decline and gradually comes to an end.

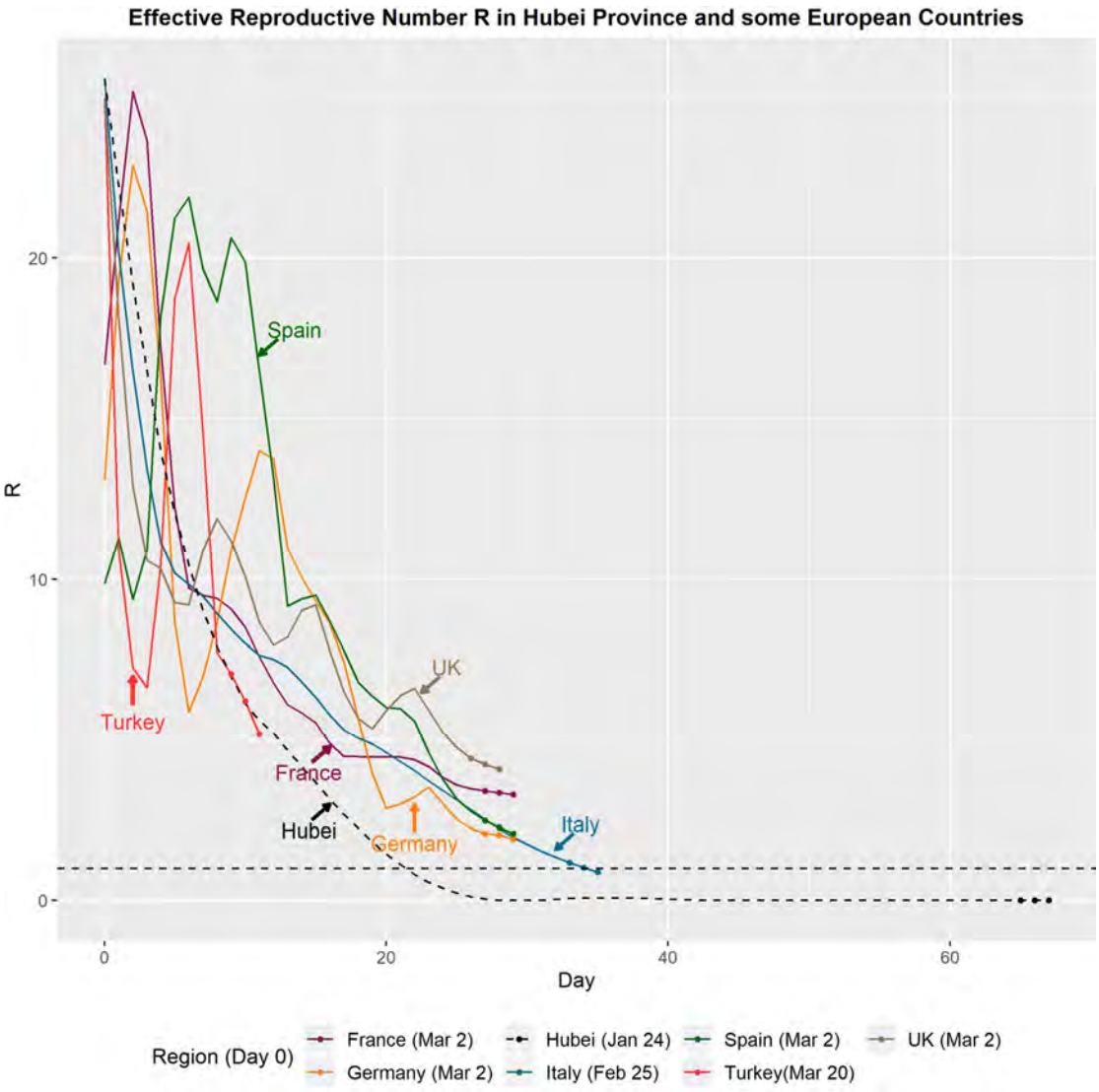

Figure 3.2. Effective Reproduction Number (R) in Europe and Hubei Province in China up to April 2, 2020, based on a 14-day Infectious Duration. Day 0 is the fifth day since the outbreak as given in the legend. Points at the end of the line refer to the value of R of the recent 3 days. The critical threshold R=1 is marked by the horizontal dashed line. Only when R is less than 1, the outbreak begins to decline and gradually comes to an end.