COVID-19 Confirmed Cases Prediction as of March 28, 2020

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[1] Chair of Entrepreneurial Risks, D-MTEC, ETH Zurich
[2] Institute of Risk Analysis, Prediction and Management (Risks-X), Academy of Interdisciplinary and Advanced Studies, Southern University of Science and Technology (SUSTech)
[3] Gavekal Intelligence Software

Contacts:
Dr. Ke WU (kwu@ethz.ch) and Prof. Dr. Didier SORNETTE (dsornette@ethz.ch)

This report updates predictions for the number of COVID-19 confirmed cases at four time horizons (1-day, 5-day, 10-day and end of the outbreak) and for various countries/regions, based on a phenomenological approach detailed in [1], i.e., employing 3 versions of the generalized logistic growth equation to model the total number of confirmed cases. The prediction results are shown in Table 1. Note that, for countries/regions at early growth stages, the predictions for long-term horizon (10-day and end of the outbreak) are highly uncertain and will vary a lot as the situation changes.

This report relies on the daily update data published by the European Centre for Disease Prevention and Control (ECDC) [2] every day at 1pm CET, reflecting data collected up to 6:00 and 10:00 CET. Thus the daily data in some countries is one day delayed compared to other online live sources.

A summary of the situation:

- In Table 1, we report the latest confirmed cases per million population and estimated outbreak progress in positive scenario (today's confirmed case divided by the estimated total final confirmed case in positive scenario). In Figure 1, we present the ensemble distribution of the estimated final total confirmed numbers per million population.
- Today's new confirmed cases in Switzerland (1390) broke the previous high of the daily new cases, which lowered its estimated outbreak progress in the positive scenario and the probability that Switzerland has well passed the inflection point[1], as diagnosed in our previous forecasts. This leaves Italy as the only country with a converged ensemble distribution of the estimated final total confirmed numbers per million people. Note that the estimated final confirmed numbers in positive scenarios tend to underestimate the final results. The reported outbreak progress serves both as a lower bound for future developments and as a guide of

[1] The inflection point is the point on the curve of the total number of confirmed cases as a function of time where the curvature changes its sign. It is equivalently the peak of the daily increase curve. If the inflection point has been passed on the curve of the total number of confirmed cases, the worst of the outbreak is over. In terms of daily number of cases, this means that the daily number of cases is decreasing.

the dynamics of the evolution of the epidemics[2].

- Spain, France, UK and Belgium have another big jump in confirmed cases today, contributing to a surge in Europe, which we have missed in all three scenario predictions yesterday (Figure 2). In Figure 2, all countries, except Italy, have distributions that have not converged, exhibiting exceedingly broad dispersion. These countries/regions are still at an early stage, following an exponential or sub-exponential growth, which leads to unreliable longer-term forecasts. The predicted ranges overlap[3] and, as time passes, we anticipate our methodology to zero in on more reliable numbers.
- Predictions for the number of confirmed cases at four time horizons (1-day, 5-day, 10-day and end of the outbreak) in three scenarios are detailed in Table 2, and one can refer to the fitting results plotted in the supplement figures for each country/region.
- We need to emphasize that reported confirmed cases are a leading indicator that is subject to a large number of extraneous variables such as sampling rate, sample targeting and reliability of testing. See note at end of this report. The real number of cases in the population are likely to be many multiples higher than those computed from confirmed tests[4].

	Confirmed per Million Population (Mar-28)	Outbreak Progress in Positive Scenario
Italy	1431	76.3%
Austria	870	59.3%
Switzerland	1421	55.9%
Spain	1371	48.5%
Netherlands	499	43.8%
France	492	36.4%
Europe	430	35.0%
Germany	586	34.5%
United States	320	30.8%
Belgium	638	<50%
Iran	395	<50%
United Kingdom	219	<50%
South Korea	184	<50%
Japan	13	<50%

Table 1. Current confirmed cases per million population and estimated outbreak progress in positive scenario (today's confirmed case divided by the estimated total final confirmed cases in positive scenario)

[2] One uncertainty with Italy (and other countries) is whether the main outbreak that is focused on the North may spread through other parts of the country. In other words, does the dynamics aggregated over a whole country represent correctly the dynamics in different parts?

[3] The real problem here is that we are not measuring growth of the epidemic. The real infections are changing with time. But so is the testing intensity.

[4] We recommend that national governments should prioritise publishing the number of daily tests conducted since the outbreak began in order to facilitate all modeling works.

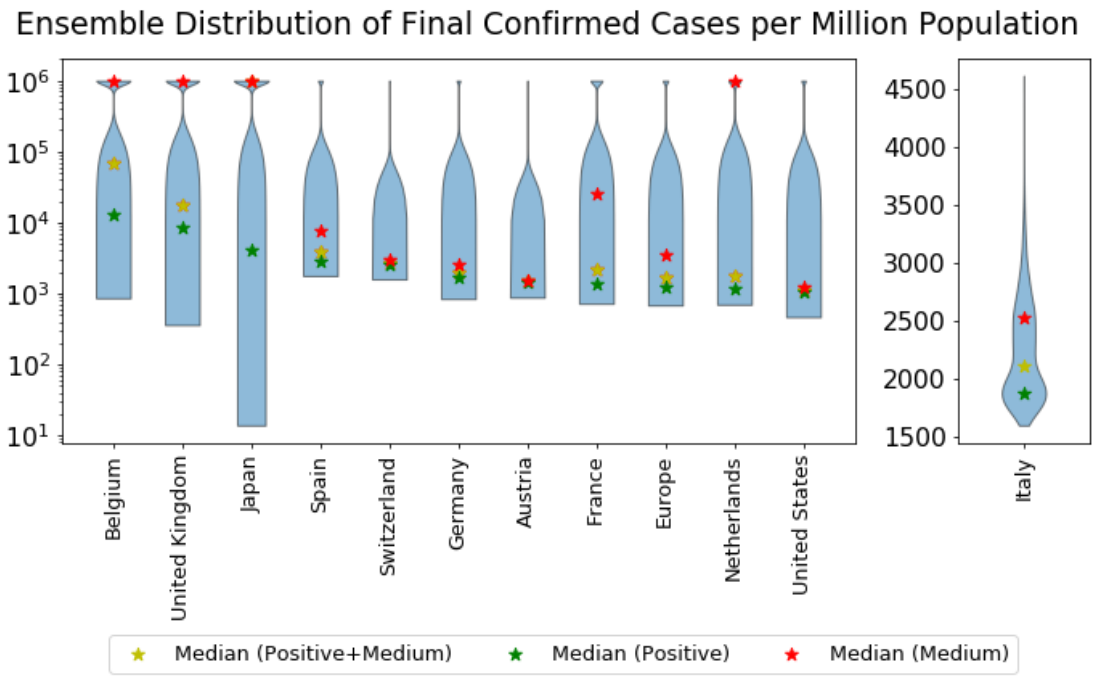


Figure 1. Violin plot of the distributions of the final total number of confirmed cases per million derived by combining the distributions of the positive and medium scenarios. The model setup in the negative scenario does not incorporate a maximum saturation number and thus cannot be used. The yellow star indicates the median prediction for the combined distribution, while the green and red stars indicate the median of the positive and of the medium scenarios respectively. Note that, where we have >1 million infections per 1 million of population, the results are deemed to be unreliable (Table 2).

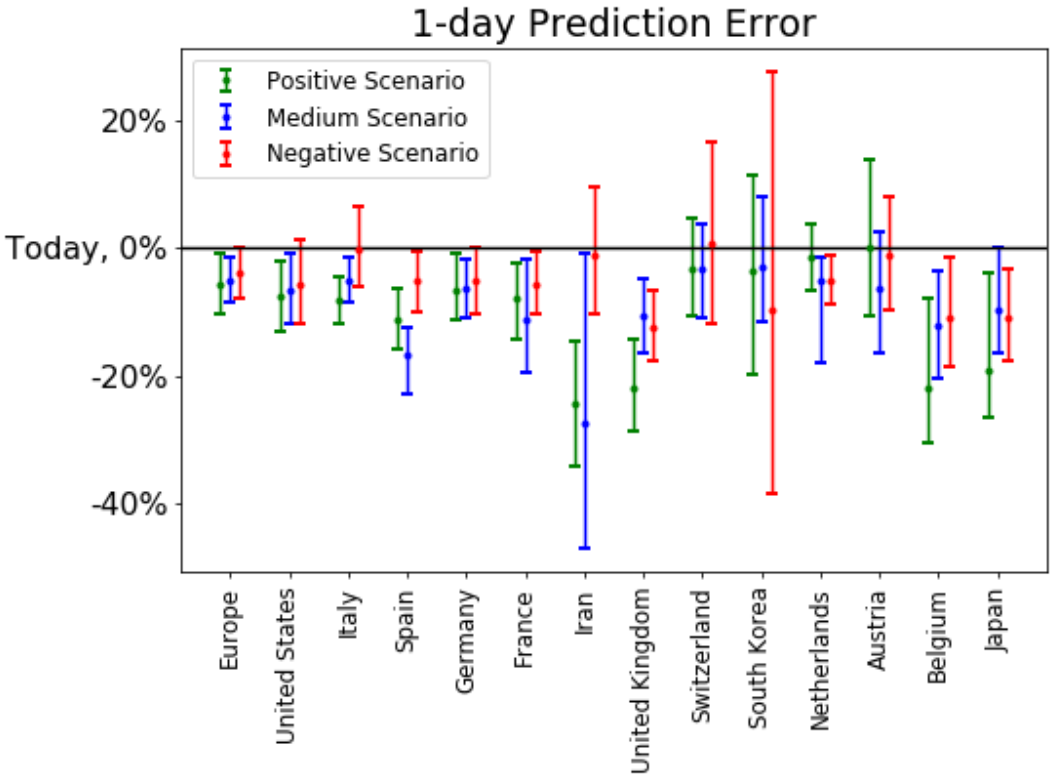


Figure 2. One-day prediction error of the 14 countries/regions. The horizontal line corresponds to today's empirical

data.

Table 2. Predictions for the number of confirmed cases at four time horizons (1-day, 5-day, 10-day and end of the outbreak) and for various countries/regions. The values in parentheses are 80% prediction intervals based on 500 simulations using a negative binomial error structure. In Today's validation column, today's empirical data is presented below yesterday's 1-day predictive interval. "Not reliable" is declared if more than 10% of the simulations produce extreme numbers (larger than total population). All numbers are in thousands.

Country	Scenario*	Today's validation	29-Mar	2-Apr	7-Apr	Final Total Confirmed
Europe	**Positive**	(288, 318) 321	343 (328, 358)	500 (459, 552)	679 (574, 845)	917 (667, 1590)
	Medium	(293, 316) 321	343 (330, 356)	525 (484, 561)	821 (667, 964)	Not Reliable
	Negative	(296, 321) 321	346 (334, 361)	547 (524, 573)	920 (862, 992)	Not Reliable
United States	**Positive**	(91.1, 103) 105	117 (111, 124)	207 (172, 259)	290 (203, 529)	340 (216, 1130)
	Medium	(92.2, 104) 105	118 (112, 124)	212 (181, 264)	317 (227, 656)	Not Reliable
	Negative	(92.2, 106) 105	120 (112, 127)	251 (227, 281)	585 (482, 747)	Not Reliable
Italy	**Positive**	(76.1, 82.5) 86.5	85.2 (81.8, 89.1)	99.2 (94, 105)	108 (101, 116)	113 (105, 124)
	Medium	(79.2, 85.4) 86.5	88.6 (85.3, 92.4)	109 (103, 115)	127 (118, 138)	153 (133, 182)
	Negative	(81.4, 92.1) 86.5	92.4 (86.5, 98)	124 (116, 132)	173 (159, 188)	Not Reliable
Spain	**Positive**	(54, 59.9) 64.1	65.8 (62.3, 69.3)	97.2 (87.4, 110)	120 (101, 156)	132 (106, 202)
	Medium	(49.4, 56.1) 64.1	68.8 (65.6, 71.9)	113 (99.8, 125)	176 (132, 238)	Not Reliable
	Negative	(57.7, 63.8) 64.1	69.7 (66.1, 73.5)	121 (113, 129)	225 (203, 251)	Not Reliable
Germany	**Positive**	(43.1, 48.2) 48.6	52.4 (49.4, 55.4)	79.8 (71, 92)	110 (87.1, 153)	141 (97.1, 351)
	Medium	(43.3, 47.7) 48.6	51.9 (49.5, 54.4)	82.2 (72.1, 91.3)	124 (91.9, 166)	Not Reliable
	Negative	(43.6, 48.6) 48.6	53.1 (50.4, 55.8)	89.7 (84.2, 95.4)	162 (148, 180)	Not Reliable
France	**Positive**	(28.2, 32.2) 33	34.7 (32.6, 37.1)	51.4 (45.8, 59.2)	70 (55.5, 96.5)	90.6 (61.8, 210)
	Medium	(26.6, 32.4) 33	34.9 (33.2, 36.7)	54.9 (50.6, 59.1)	90.8 (70.3, 104)	Not Reliable
	Negative	(29.5, 32.8) 33	35.2 (33.5, 36.9)	56.3 (53.4, 59.6)	95.9 (88.4, 106)	Not Reliable
United Kingdom	**Positive**	(10.4, 12.5) 14.5	15.6 (14.7, 16.4)	34.2 (28.5, 39.4)	83.1 (46.5, 122)	Not Reliable
	Medium	(12.1, 13.8) 14.5	15.6 (14.7, 16.5)	34.6 (26.8, 39.2)	91.7 (39.2, 118)	Not Reliable
	Negative	(12, 13.6) 14.5	15.6 (14.8, 16.5)	35.5 (32.4, 39.5)	96.2 (78.4, 123)	Not Reliable
Switzerland	**Positive**	(10.8, 12.7) 12.1	13.4 (12.1, 14.7)	17.1 (14.7, 19.8)	19.8 (16.2, 25.9)	21.7 (16.8, 35.9)

	Medium	(10.8, 12.5) 12.1	13.4 (12.3, 14.3)	17.4 (15.3, 19.9)	21.3 (17.2, 27.8)	25.9 (18.2, 63.4)
	Negative	(10.7, 14.1) 12.1	13.8 (12.1, 15.4)	20.4 (17.7, 23)	31.1 (26, 37.2)	Not Reliable
Netherlands	**Positive**	(8.03, 8.91) 8.6	9.86 (9.3, 10.4)	14.1 (12.4, 16.5)	17.5 (14.1, 23.8)	19.6 (14.9, 32.8)
	Medium	(7.06, 8.48) 8.6	9.29 (8.85, 9.73)	15.3 (13.6, 16.7)	26.6 (19, 31)	Not Reliable
	Negative	(7.84, 8.5) 8.6	9.39 (8.96, 9.81)	15.8 (14.9, 16.8)	28.2 (25.7, 31.2)	Not Reliable
Austria	**Positive**	(6.87, 8.78) 7.7	8.08 (7.32, 8.87)	10.6 (9.22, 12.7)	12.2 (9.99, 16.8)	13 (10.2, 20.8)
	Medium	(6.43, 7.9) 7.7	8.08 (7.46, 8.77)	10.8 (9.65, 12.8)	12.5 (10.7, 17.8)	13.4 (11.1, 28.7)
	Negative	(6.94, 8.31) 7.7	8.31 (7.48, 9.36)	13.2 (11.5, 15.2)	21.3 (17.8, 27.9)	Not Reliable
Belgium	**Positive**	(5.06, 6.71) 7.28	7.55 (7.02, 8.16)	13.7 (11.2, 15.9)	24.9 (14.3, 36)	Not Reliable
	Medium	(5.78, 7.02) 7.28	7.8 (7.25, 8.45)	14.8 (12, 17.4)	32.1 (16.4, 44.9)	Not Reliable
	Negative	(5.94, 7.18) 7.28	7.66 (7.12, 8.3)	14.5 (13.1, 16.1)	29.8 (24.7, 36.5)	Not Reliable
Japan	**Positive**	(1.24, 1.62) 1.69	1.66 (1.5, 1.82)	2.21 (1.94, 2.5)	3.13 (2.45, 3.75)	Not Reliable
	Medium	(1.41, 1.7) 1.69	1.58 (1.44, 1.75)	2.18 (1.95, 2.47)	3.25 (2.7, 3.81)	Not Reliable
	Negative	(1.4, 1.64) 1.69	1.58 (1.44, 1.75)	2.2 (1.97, 2.47)	3.33 (2.87, 3.82)	Not Reliable
Iran	**Positive**	(21.3, 27.6) 32.3	27.2 (24.1, 31.3)	34.3 (28.5, 45.1)	39.6 (30.9, 65.1)	Not Reliable
	Medium	(17.1, 32.1) 32.3	34.6 (32.2, 37.7)	43.5 (39.5, 47.5)	55.9 (47.9, 62.6)	Not Reliable
	Negative	(29, 35.4) 32.3	35 (32.3, 37.8)	44.5 (41.2, 48.5)	58.5 (53.3, 64.1)	Not Reliable
South Korea	**Positive**	(7.61, 10.6) 9.48	9.36 (8.03, 11)	9.36 (8.03, 11)	9.36 (8.03, 11)	Not Reliable
	Medium	(8.39, 10.2) 9.48	9.46 (8.55, 10.5)	9.48 (8.56, 10.5)	9.49 (8.57, 10.5)	Not Reliable
	Negative	(5.83, 12.1) 9.48	8.85 (5.84, 12.7)	10.1 (6.83, 14.6)	11.6 (7.86, 17.4)	Not Reliable

* Note:

- The scenarios are based on the final total confirmed numbers. The positive and medium scenarios are derived from the Generalized Logistic Model and the Logistic Model. The model with the lower mean predicted final total confirmed number K, is classified as the positive scenario, and the other one is classified as the medium scenario. The negative scenario is based on the Generalized Growth model, which should only describe the early stage of the epidemic outbreak and is therefore least reliable for countries in the more mature stage.
- Trajectories from Iran and South Korea have largely deviated from a typical logistic type growth (S curve), and can't be properly described by our models. Although we still report the

results of the calibrations for these two countries in Table 1, they should not be taken as reliable in all scenarios and time horizons. In the case of South Korea, the bad fits could be due to the increase rate of testing and/or, less likely, to a resurgence of an outbreak. In the case of Iran, it is probably a result of unreliable reported data.

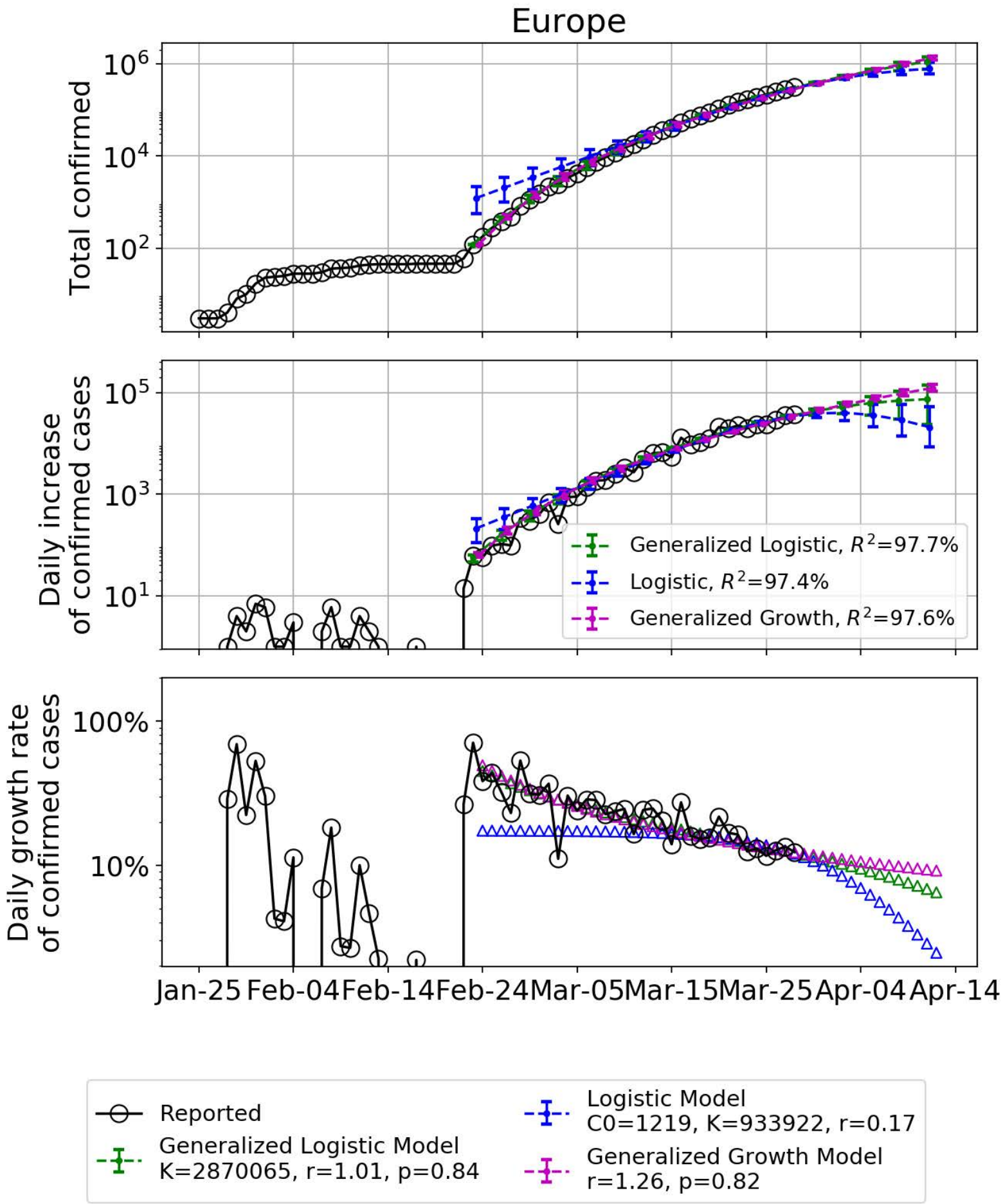
Limitations of using the statistics of reported confirmed number

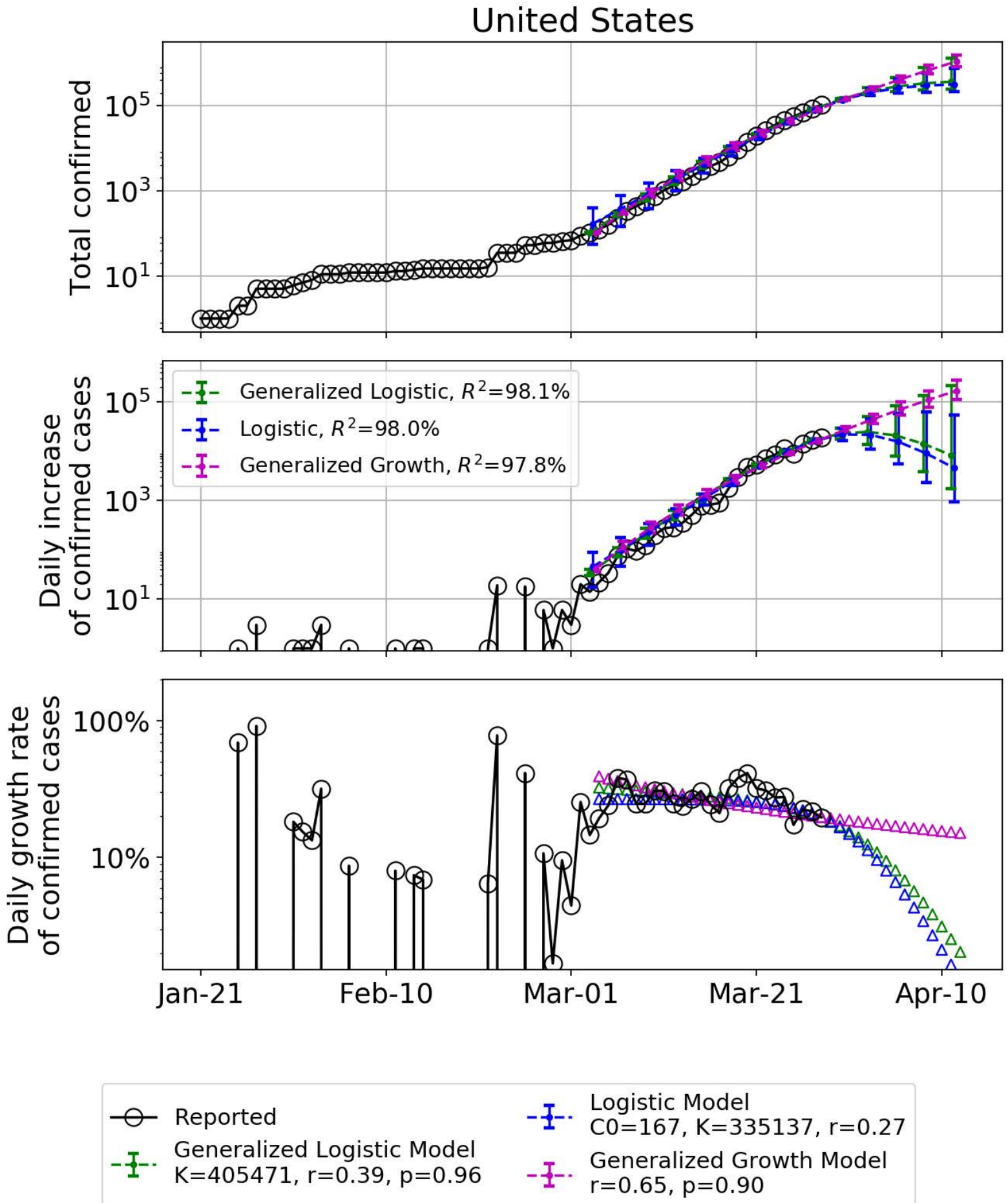
It is important to understand what our prediction models show. The predictions are based on cases identified on the basis of testing and they therefore predict the numbers of future positive tests. Relating positive test results to real levels of infection is subject to a large number of biases. It is a fact that the real number of infections is far higher than those recorded in positive tests since only a tiny fraction of any population has been tested. It is also the case that, in most countries, testing is biased towards those who think they are infected. The first bias, therefore, will underestimate the real number of infections while the second bias will tend to overestimate since it is biased towards those who think they are ill.

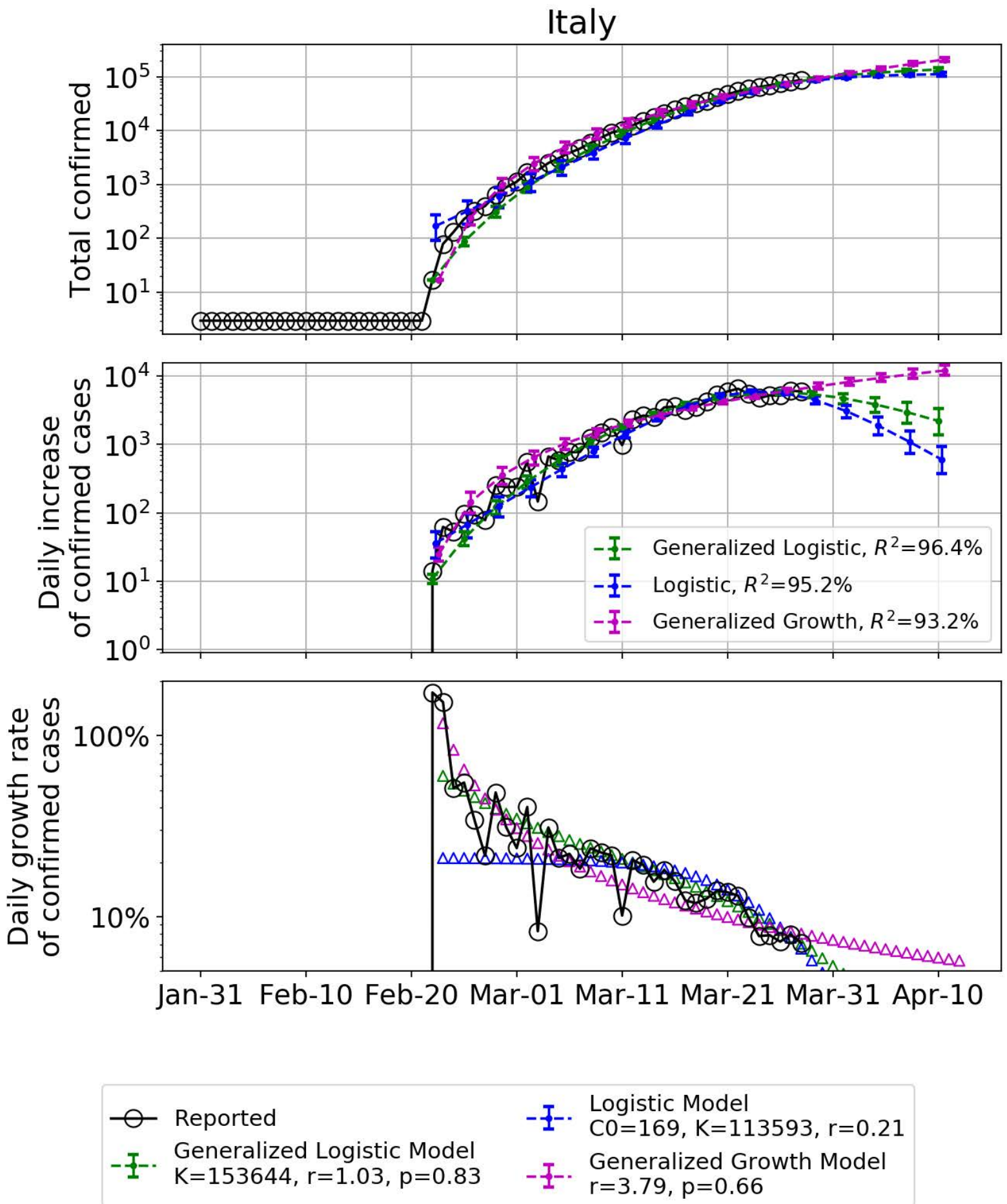
There are further complications. Depending on the testing protocols used, in some instances false positive results have been obtained. In other words, someone without the disease tested positive, probably because they were infected with some other coronavirus. And in other cases, false negative results were obtained, as was the case with the early testing deployed in the USA.
One final complication is the fact that tests are conducted sequentially over time. They do not represent a snapshot of a day in time. Many of those tested early, giving a negative result, may today get a positive result. And many, who tested positive early on, may today be cured.
We anticipate that, over time, our methodology will improve and will provide a more accurate picture of the true levels of infection and where they are headed.

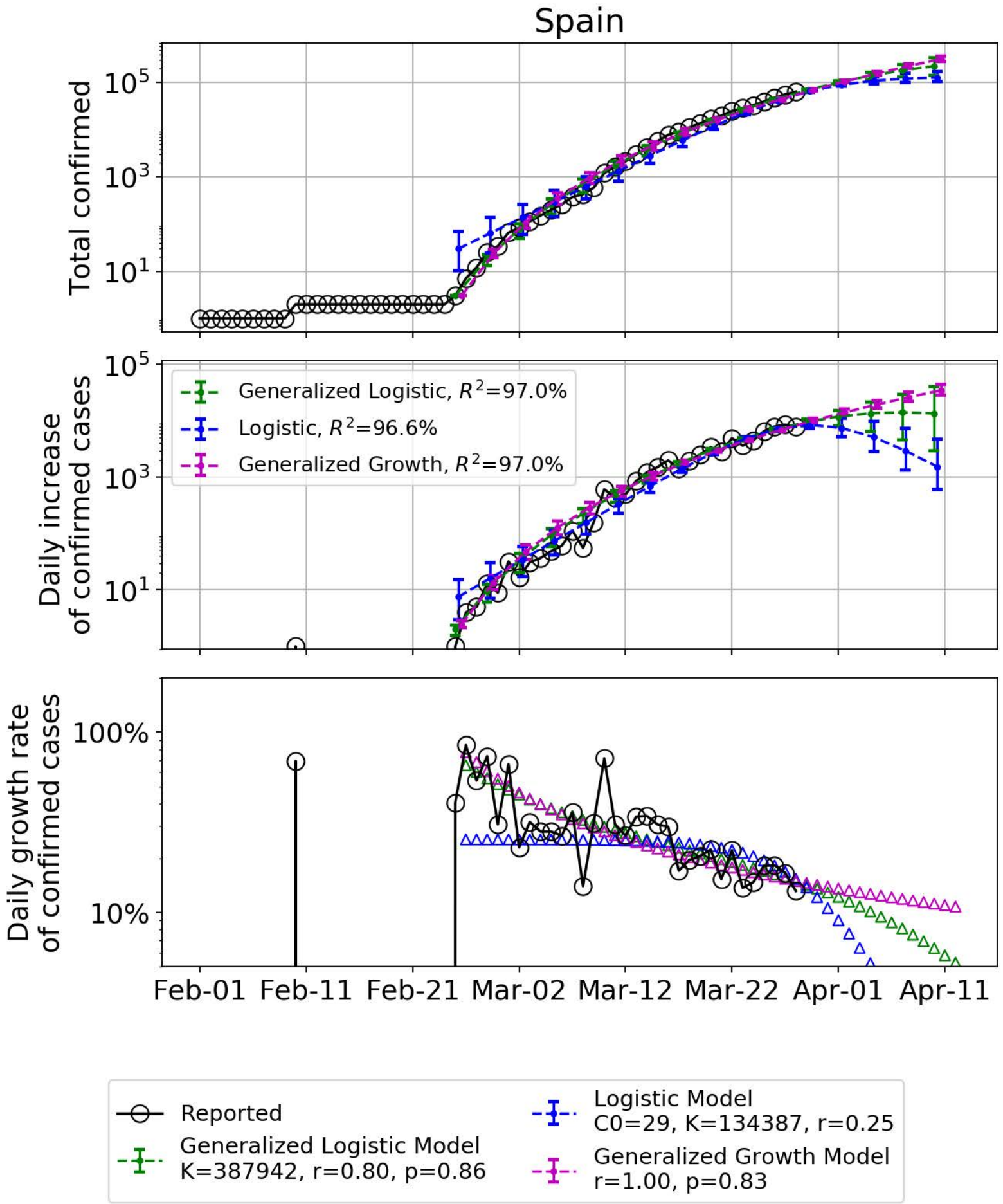
[1] Ke Wu, Didier Darcet, Qian Wang and Didier Sornette, Generalized logistic growth modeling of the COVID-19 outbreak in 29 provinces in China and in the rest of the world, preprint at http://arxiv.org/abs/2003.05681 and
medRxiv: https://medrxiv.org/cgi/content/short/2020.03.11.20034363v1

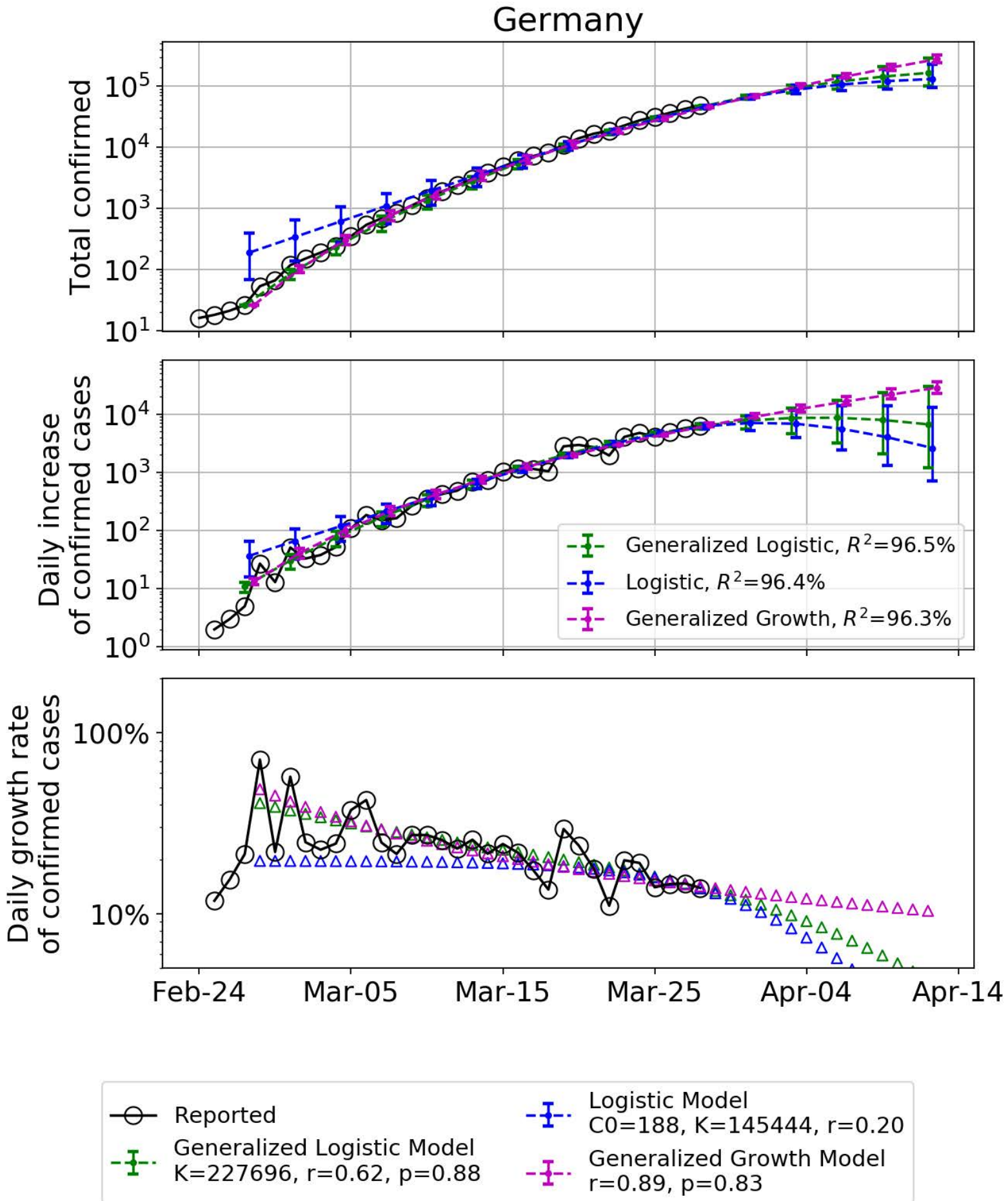
[2] https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases

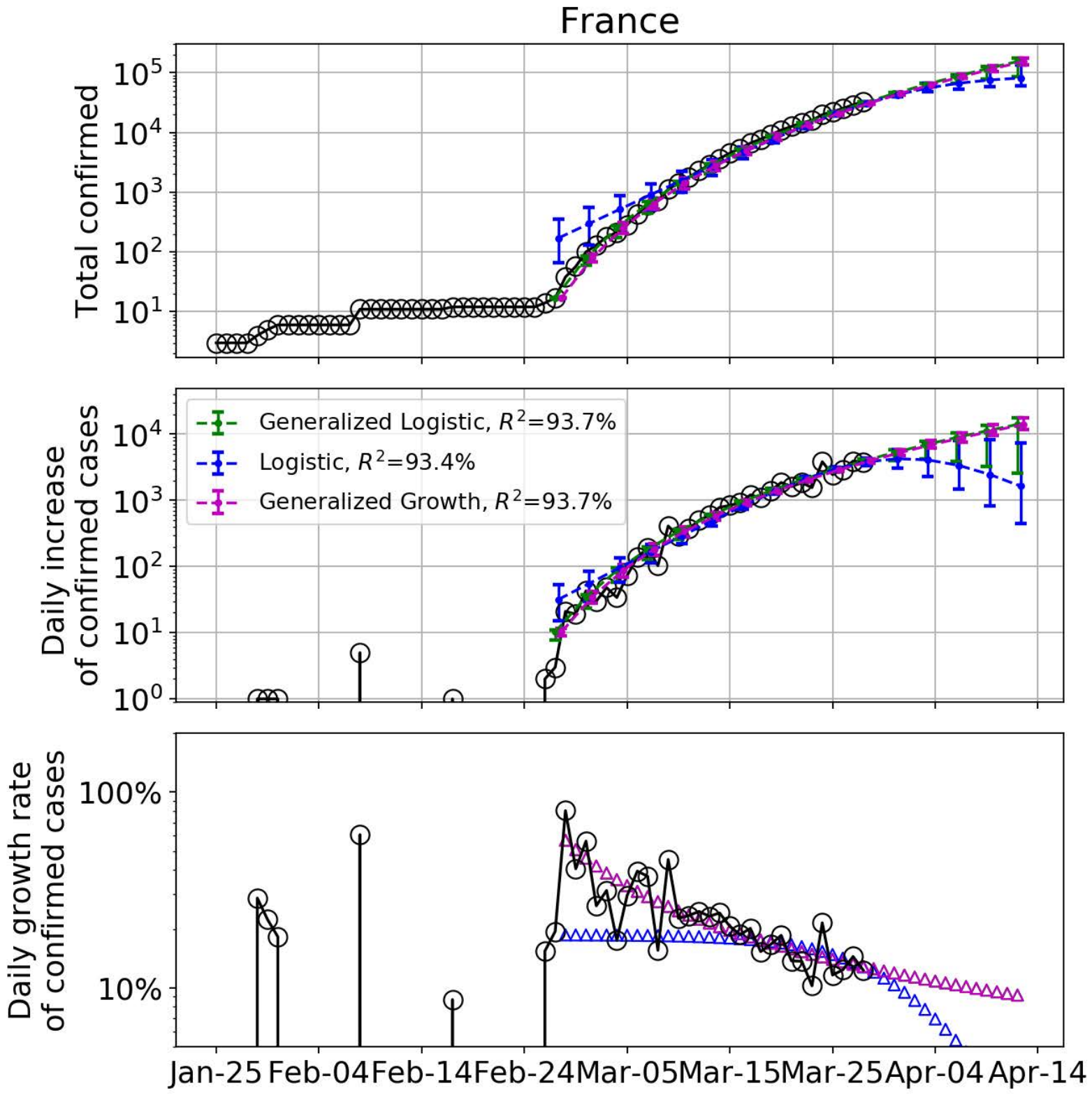

Europe
Total confirmed
10^6
10^4
10^2
Daily increase of confirmed cases
10^5
10^3
10^1
Generalized Logistic, R^2=97.7%
Logistic, R^2=97.4%
Generalized Growth, R^2=97.6%
Daily growth rate of confirmed cases
100%
10%
Jan-25
Feb-04
Feb-14
Feb-24
Mar-05
Mar-15
Mar-25
Apr-04
Apr-14
Reported
Generalized Logistic Model
K=2870065, r=1.01, p=0.84
Logistic Model
C0=1219, K=933922, r=0.17
Generalized Growth Model
r=1.26, p=0.82

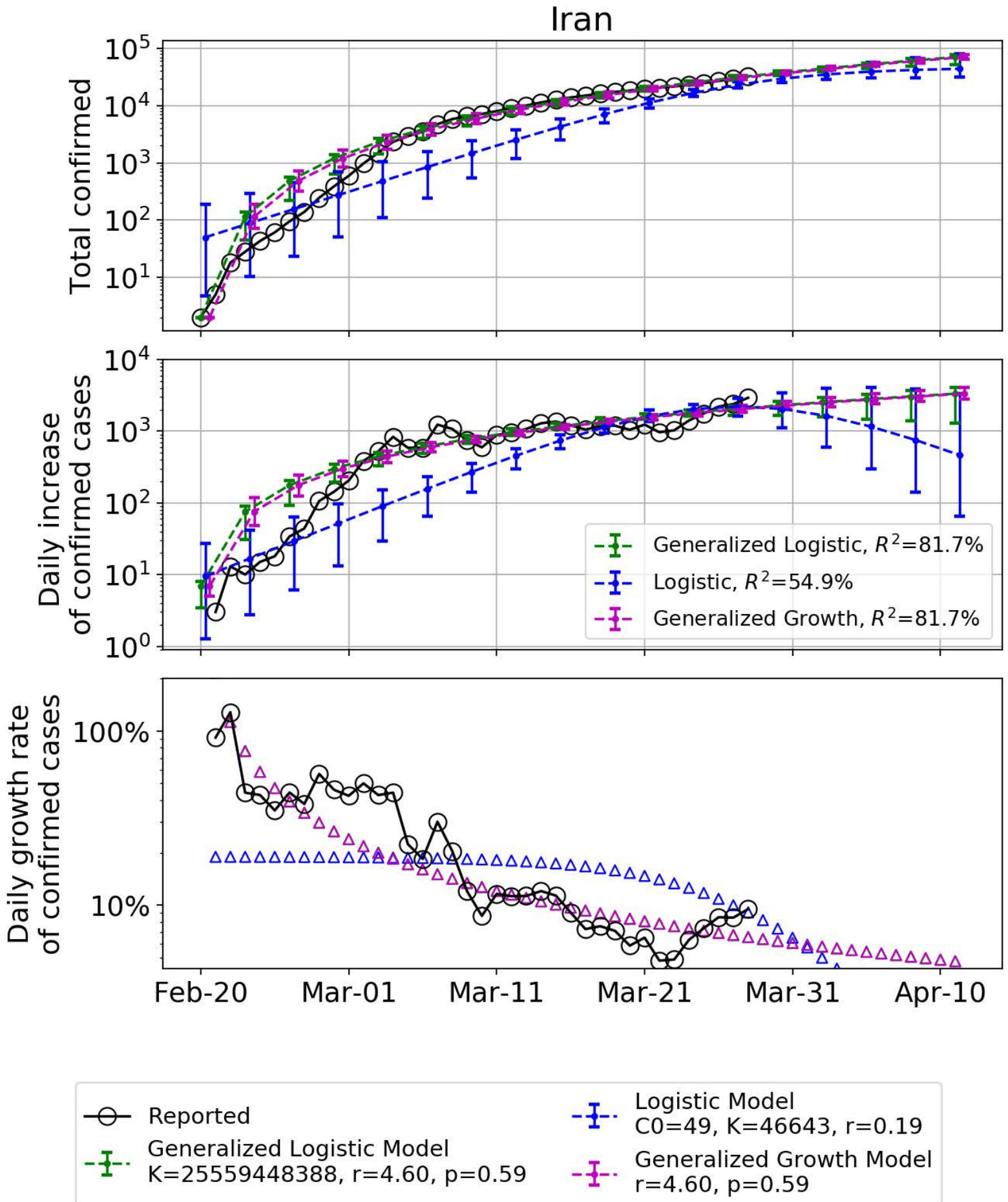

United States
Total confirmed
10^5
10^3
10^1
Daily increase of confirmed cases
Generalized Logistic, R^2=98.1%
Logistic, R^2=98.0%
Generalized Growth, R^2=97.8%
Daily growth rate of confirmed cases
100%
10%
Jan-21
Feb-10
Mar-01
Mar-21
Apr-10
Reported
Generalized Logistic Model
K=405471, r=0.39, p=0.96
Logistic Model
C0=167, K=335137, r=0.27
Generalized Growth Model
r=0.65, p=0.90

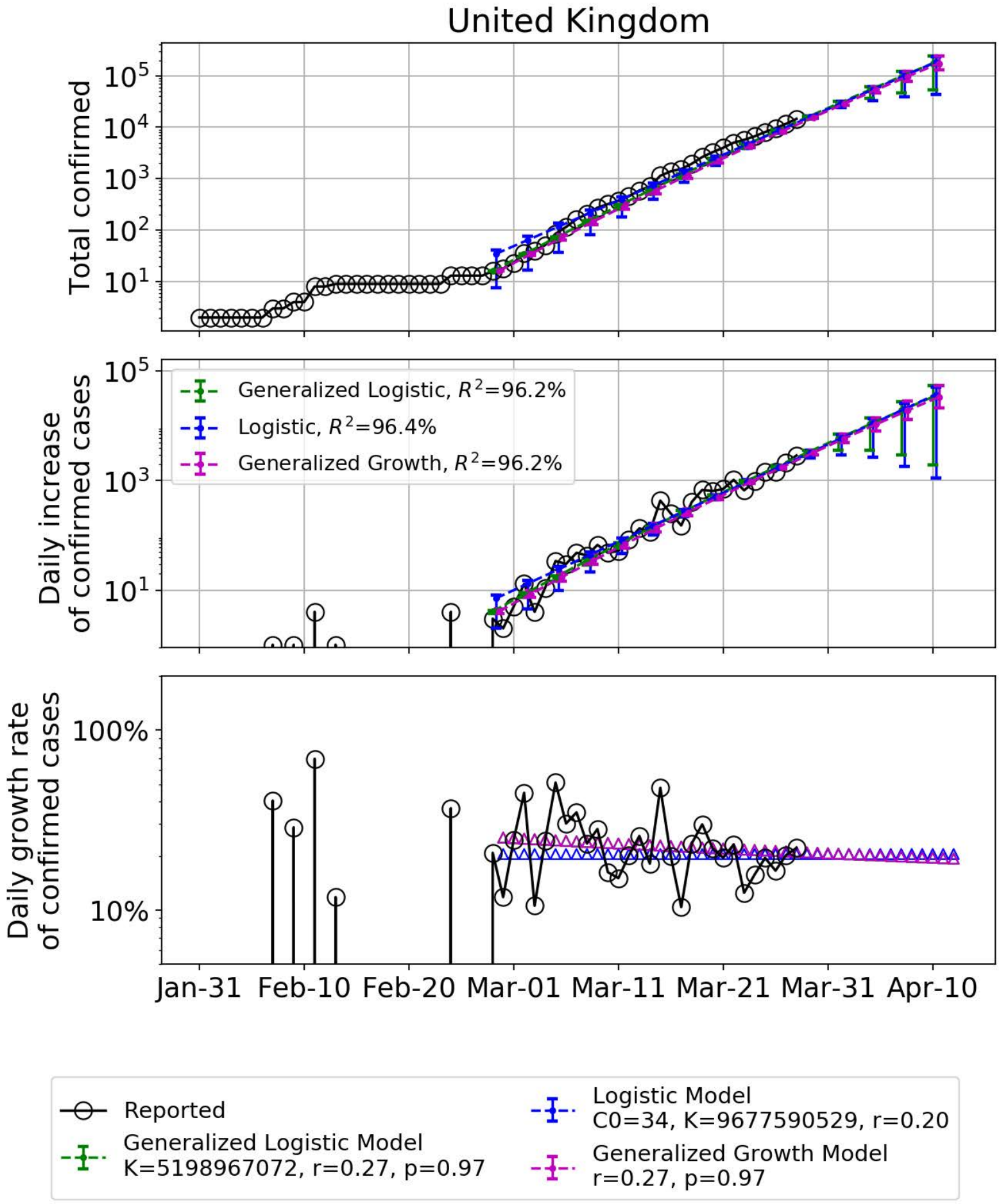

Italy
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=96.4%
Logistic, R^2=95.2%
Generalized Growth, R^2=93.2%
Jan-31
Feb-10
Feb-20
Mar-01
Mar-11
Mar-21
Mar-31
Apr-10
Reported
Generalized Logistic Model
K=153644, r=1.03, p=0.83
Logistic Model
C0=169, K=113593, r=0.21
Generalized Growth Model
r=3.79, p=0.66

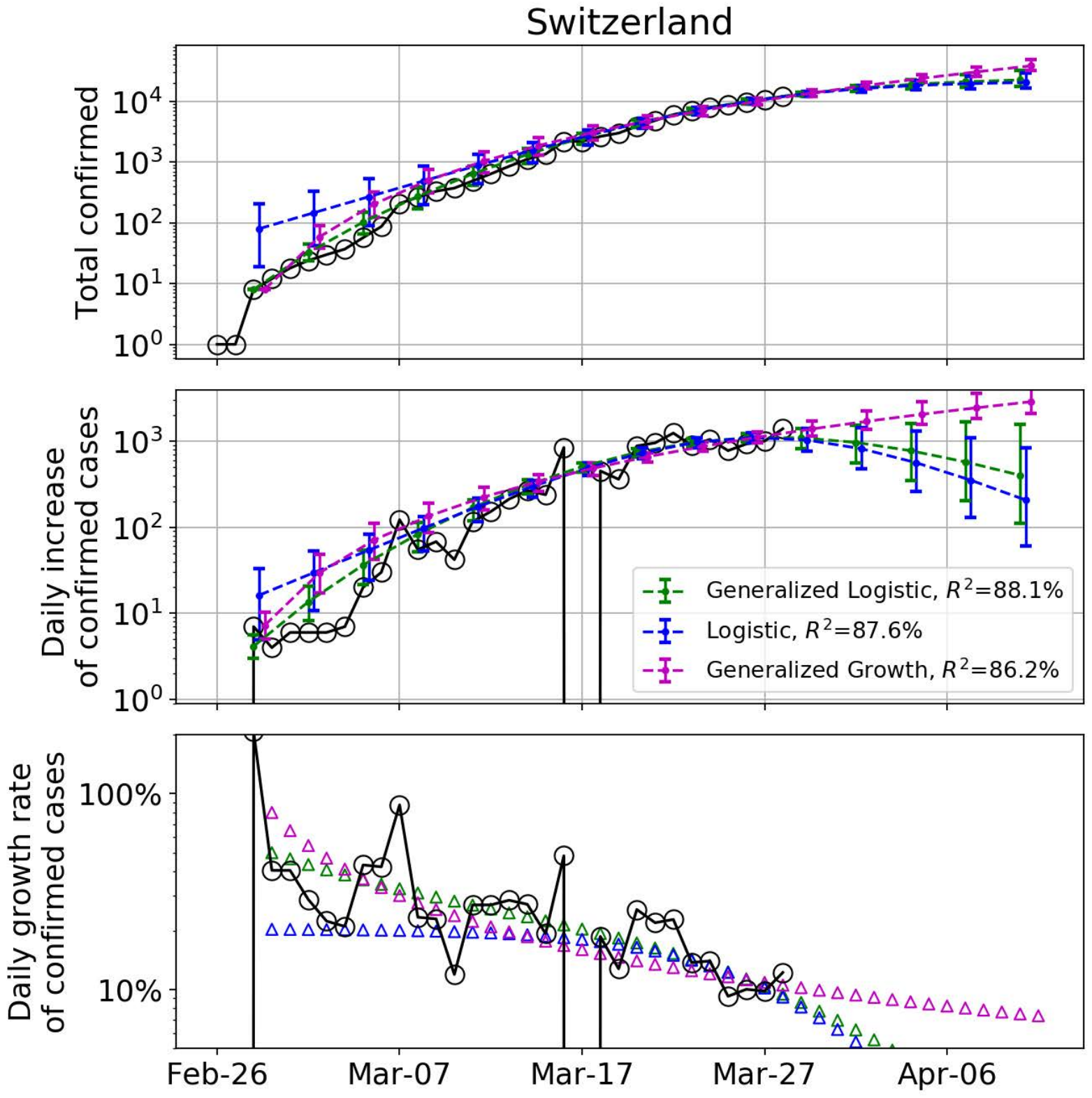

Spain
Total confirmed
10^5
10^3
10^1
Daily increase of confirmed cases
Generalized Logistic, R^2=97.0%
Logistic, R^2=96.6%
Generalized Growth, R^2=97.0%
Daily growth rate of confirmed cases
100%
10%
Feb-01
Feb-11
Feb-21
Mar-02
Mar-12
Mar-22
Apr-01
Apr-11
Reported
Generalized Logistic Model
K=387942, r=0.80, p=0.86
Logistic Model
C0=29, K=134387, r=0.25
Generalized Growth Model
r=1.00, p=0.83

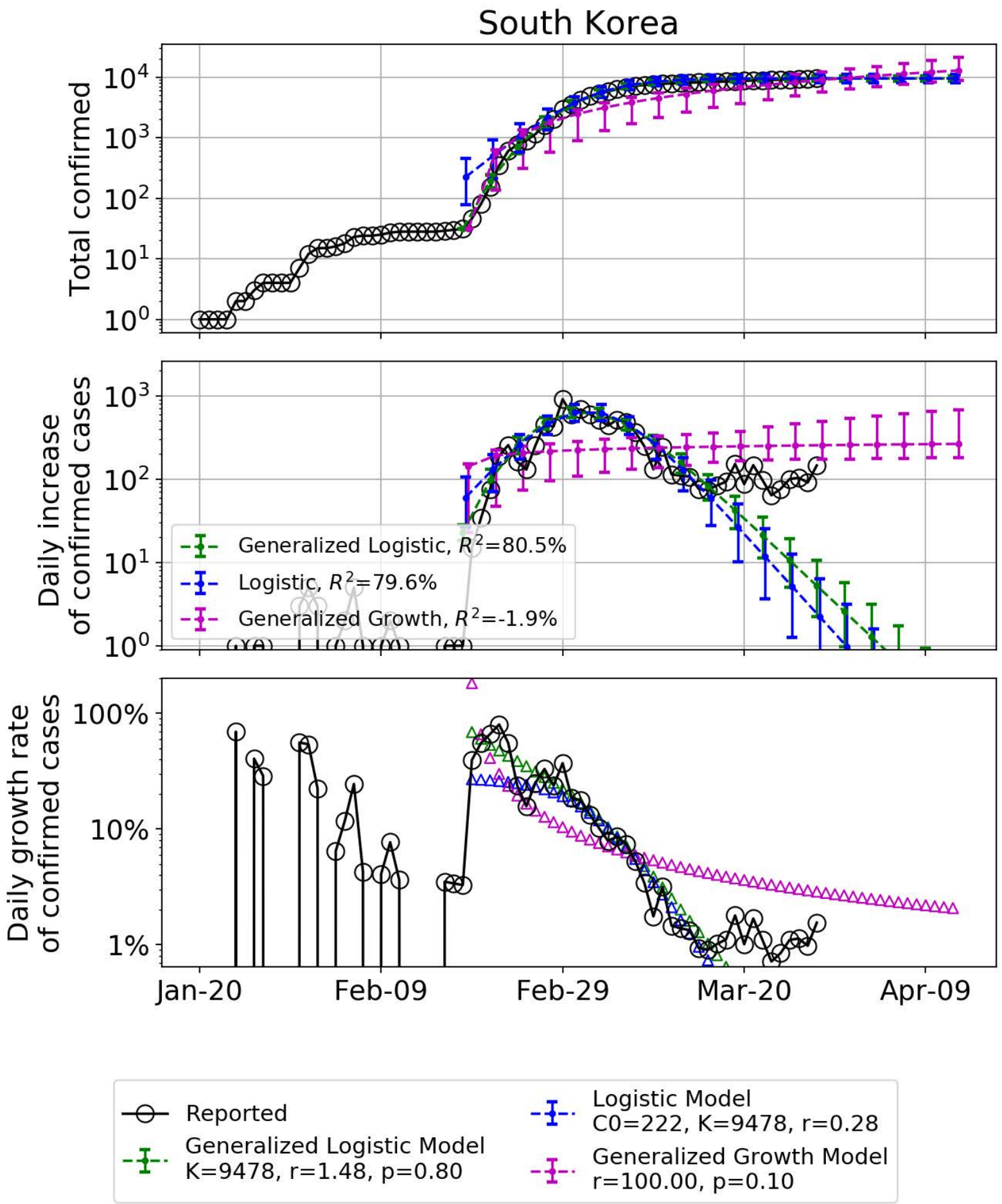

Germany
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=96.5%
Logistic, R^2=96.4%
Generalized Growth, R^2=96.3%
Feb-24
Mar-05
Mar-15
Mar-25
Apr-04
Apr-14
Reported
Generalized Logistic Model
K=227696, r=0.62, p=0.88
Logistic Model
C0=188, K=145444, r=0.20
Generalized Growth Model
r=0.89, p=0.83

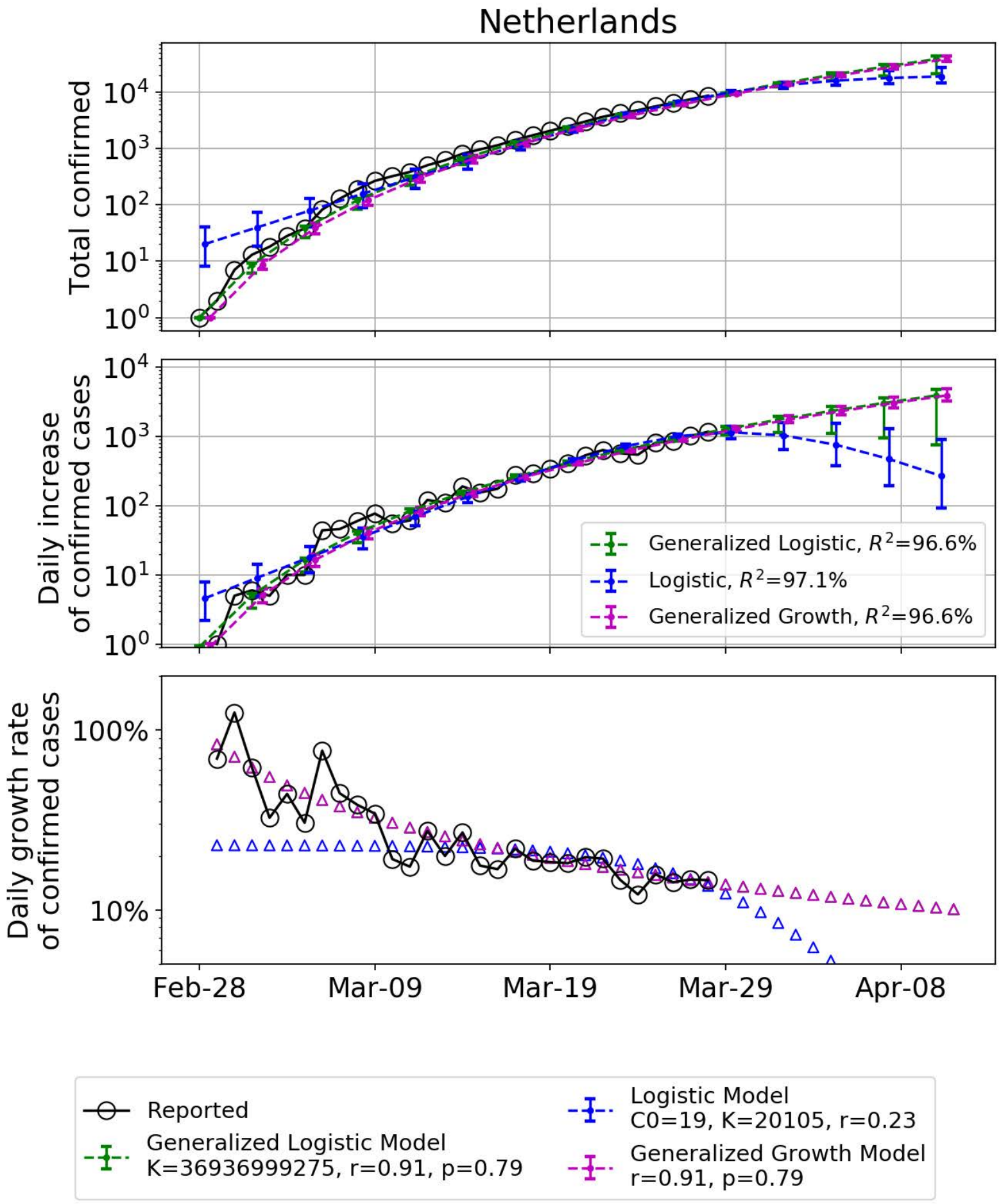

France
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=93.7%
Logistic, R^2=93.4%
Generalized Growth, R^2=93.7%
Jan-25
Feb-04
Feb-14
Feb-24
Mar-05
Mar-15
Mar-25
Apr-04
Apr-14
Reported
Generalized Logistic Model
K=16059143713, r=1.09, p=0.79
Logistic Model
C0=169, K=91649, r=0.19
Generalized Growth Model
r=1.09, p=0.79

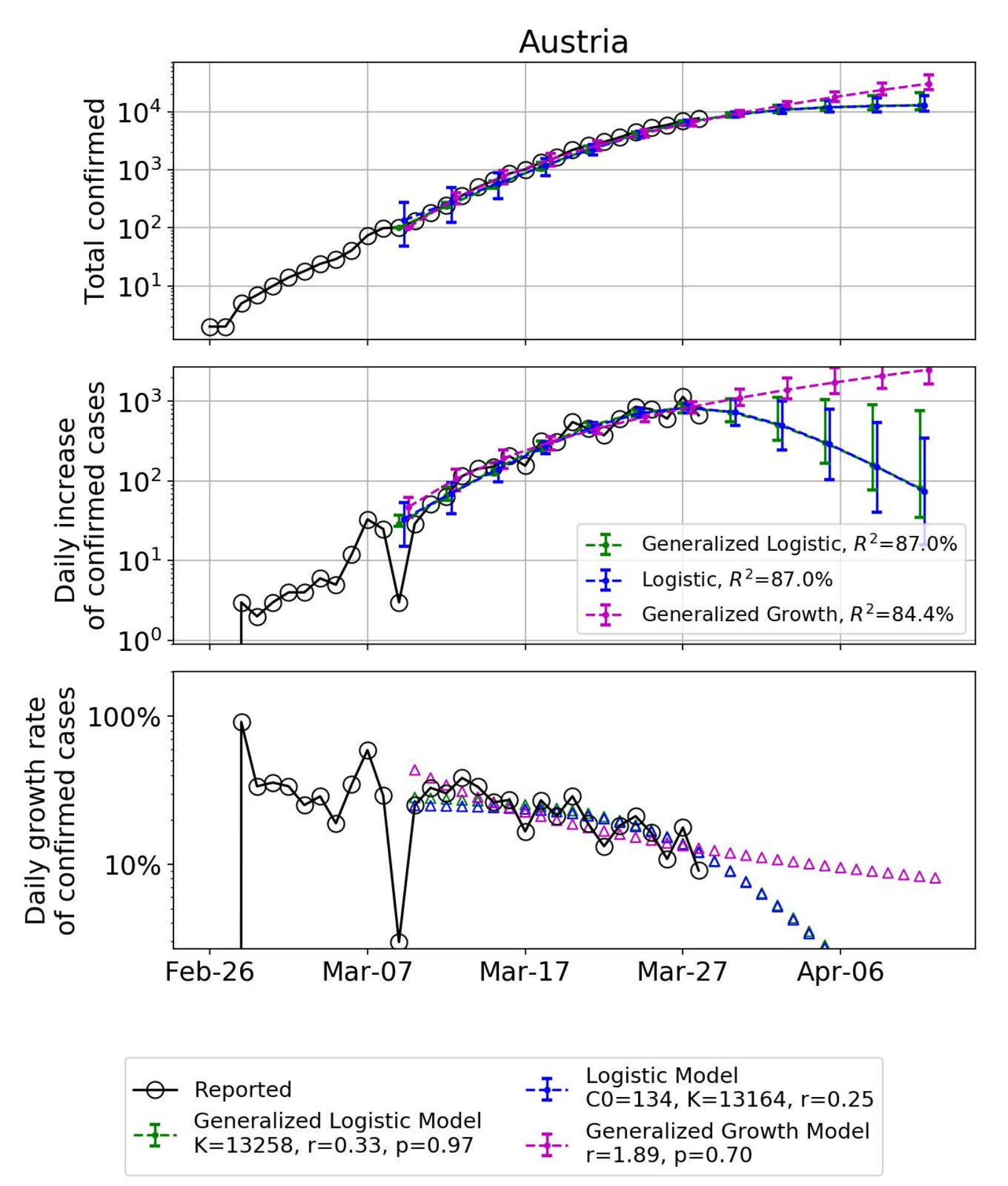

Iran
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=81.7%
Logistic, R^2=54.9%
Generalized Growth, R^2=81.7%
100%
10%
Feb-20
Mar-01
Mar-11
Mar-21
Mar-31
Apr-10
Reported
Generalized Logistic Model
K=25559448388, r=4.60, p=0.59
Logistic Model
C0=49, K=46643, r=0.19
Generalized Growth Model
r=4.60, p=0.59

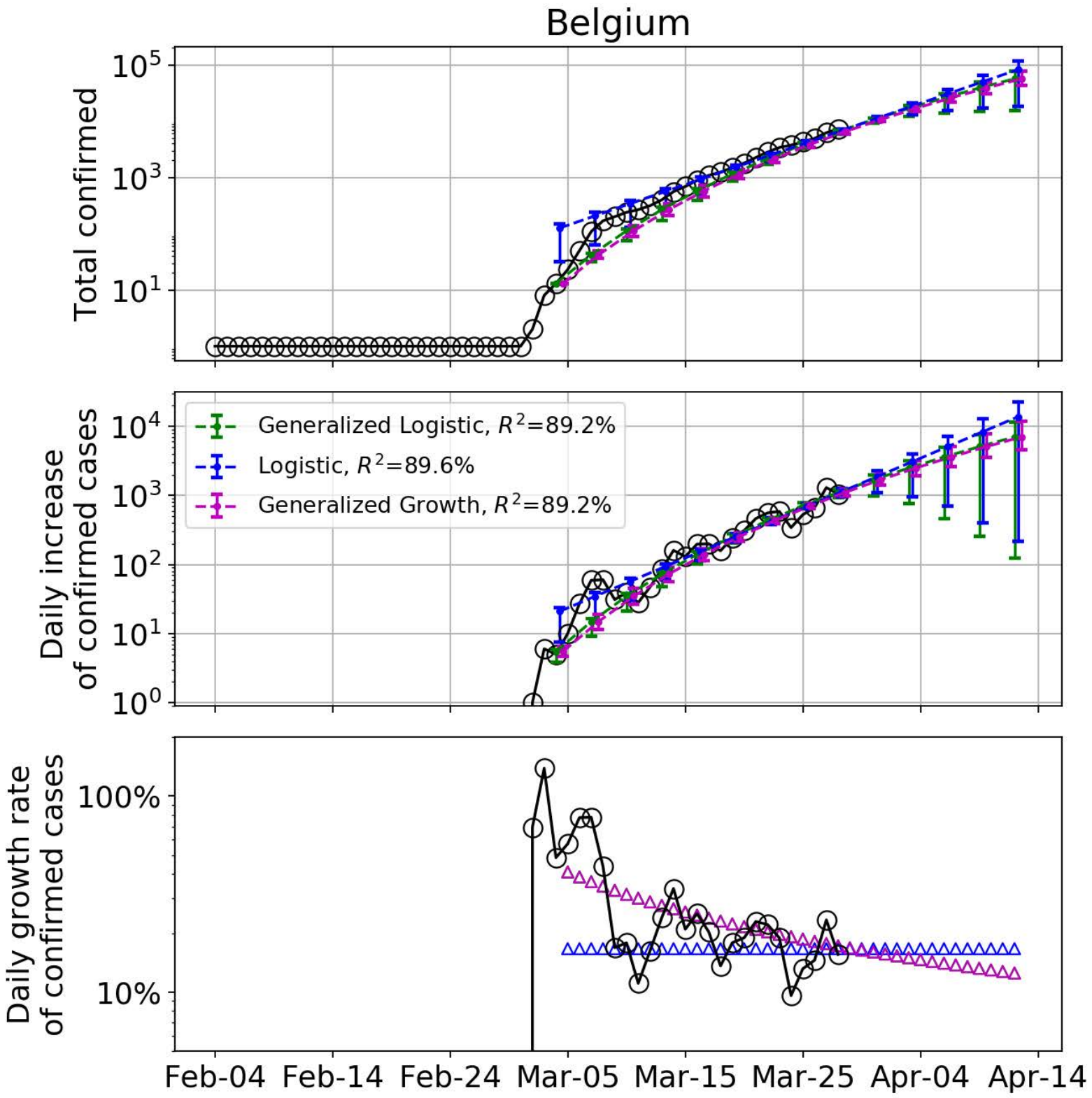

United Kingdom
Total confirmed
10^5
10^4
10^3
10^2
10^1
Daily increase of confirmed cases
Generalized Logistic, R^2=96.2%
Logistic, R^2=96.4%
Generalized Growth, R^2=96.2%
Daily growth rate of confirmed cases
100%
10%
Jan-31
Feb-10
Feb-20
Mar-01
Mar-11
Mar-21
Mar-31
Apr-10
Reported
Generalized Logistic Model
K=5198967072, r=0.27, p=0.97
Logistic Model
C0=34, K=9677590529, r=0.20
Generalized Growth Model
r=0.27, p=0.97


Switzerland
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=88.1%
Logistic, R^2=87.6%
Generalized Growth, R^2=86.2%
100%
10%
Feb-26
Mar-07
Mar-17
Mar-27
Apr-06
Reported
Generalized Logistic Model
K=25393, r=0.71, p=0.85
Logistic Model
C0=79, K=21600, r=0.20
Generalized Growth Model
r=1.67, p=0.71


South Korea
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=80.5%
Logistic, R^2=79.6%
Generalized Growth, R^2=-1.9%
Jan-20
Feb-09
Feb-29
Mar-20
Apr-09
Reported
Generalized Logistic Model
K=9478, r=1.48, p=0.80
Logistic Model
C0=222, K=9478, r=0.28
Generalized Growth Model
r=100.00, p=0.10


Netherlands
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=96.6%
Logistic, R^2=97.1%
Generalized Growth, R^2=96.6%
Feb-28
Mar-09
Mar-19
Mar-29
Apr-08
Reported
Generalized Logistic Model
K=36936999275, r=0.91, p=0.79
Logistic Model
C0=19, K=20105, r=0.23
Generalized Growth Model
r=0.91, p=0.79


Austria
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=87.0%
Logistic, R^2=87.0%
Generalized Growth, R^2=84.4%
Feb-26
Mar-07
Mar-17
Mar-27
Apr-06
Reported
Generalized Logistic Model
K=13258, r=0.33, p=0.97
Logistic Model
C0=134, K=13164, r=0.25
Generalized Growth Model
r=1.89, p=0.70

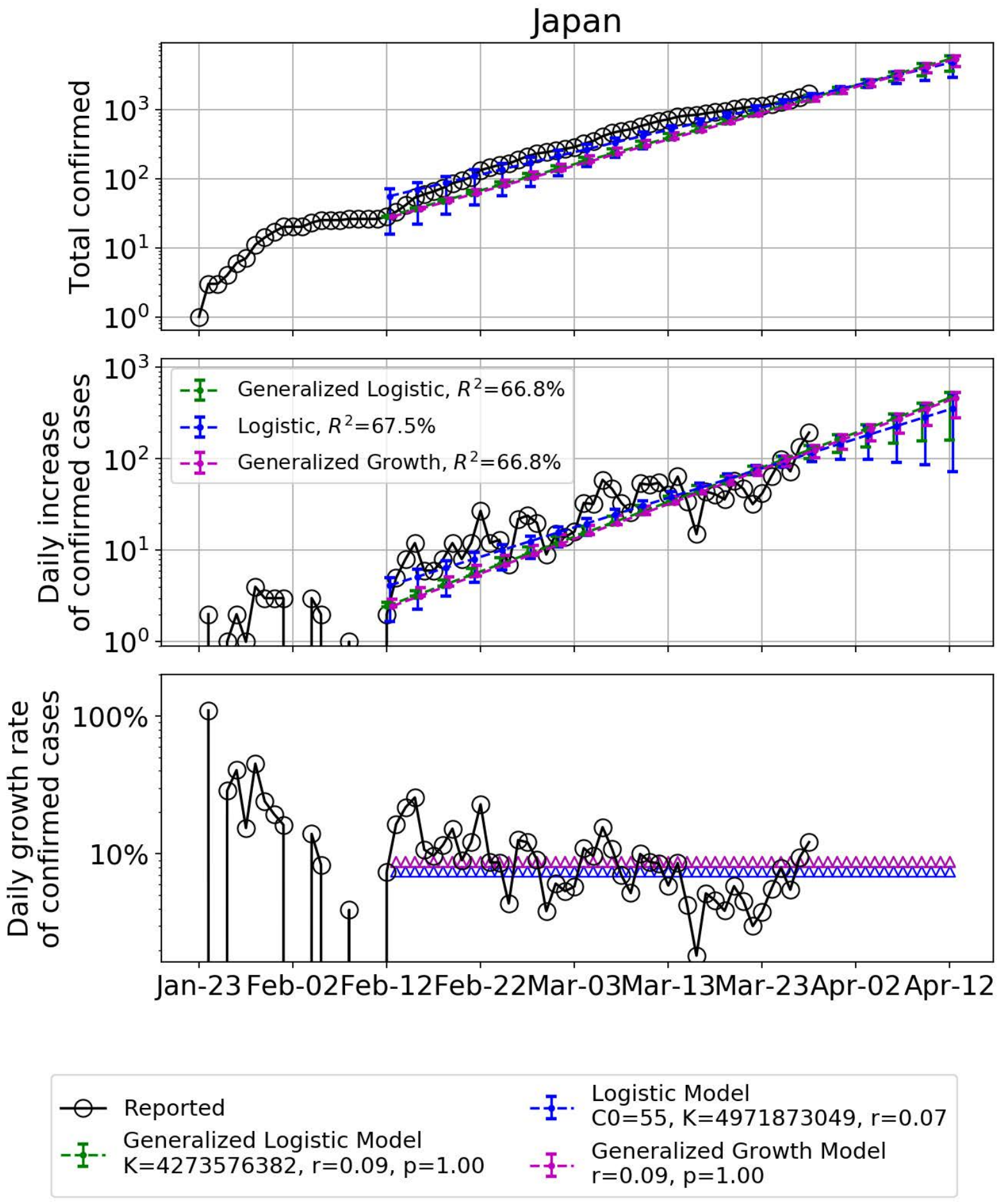


Reported

Generalized Logistic Model
K=16487628613, r=0.61, p=0.85

Logistic Model
C0=125, K=9494435337, r=0.17

Generalized Growth Model
r=0.61, p=0.85


Japan
Total confirmed
Daily increase of confirmed cases
Daily growth rate of confirmed cases
Generalized Logistic, R^2=66.8%
Logistic, R^2=67.5%
Generalized Growth, R^2=66.8%
Jan-23
Feb-02
Feb-12
Feb-22
Mar-03
Mar-13
Mar-23
Apr-02
Apr-12
Reported
Generalized Logistic Model
K=4273576382, r=0.09, p=1.00
Logistic Model
C0=55, K=4971873049, r=0.07
Generalized Growth Model
r=0.09, p=1.00