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Modelling the effect of lockdown on COVID-19 pandemic in 22 countries and cities

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Abstract

Backgrounds: COVID-19 is currently spreading around the world, and the cumulative number of cases worldwide exceeded 5 million on 23 May 2020 (10:00 GMT+2). At present, many countries or cities have implemented lockdown measures. This study evaluated the inhibitory effect of lockdown measures on the pandemic by the use of lockdown or similar lockdown in 22 countries or cities.

Methods: An SEIQR epidemiological model was developed to capture the transmission dynamics of COVID-19. With the data related to COVID-19 from 22 countries or cities, the optimal parameters of the model were estimated, respectively.

Results: The average basic reproduction numbers of 22 countries or cities were between 1.5286-3.8067. And Russia Federation, Spain, Italy, France, Germany, the United Kingdom, Singapore, the United States of New York and the United States of New Jersey were hardest hit by COVID-19.

Conclusion: Although the pandemic has not been fundamentally controlled for a short time after lockdown, lockdown was proved to be an extremely effective control measure, which significantly scaled the number of patients down, thereby reduced the harmfulness of the

pandemic.

Keywords: COVID-19; Lockdown; SEIQR model; Basic reproduction number

1 Introduction

Coronavirus disease (COVID-19) is a unusual coronavirus with strong infectiousness and high mortality [1]. Wuhan Municipal Health Commission, China, reported a cluster of cases of pneumonia in Wuhan, Hubei Province in December 2019. Gradually, more and more people fall ill who have the same symptom in other countries. The COVID-19 pandemic has been lasting around 5 months all around the world. There were 5,488,825 confirmed cases and the 349,095 deaths across the planet on 27 May 2020 according to the WHO (10:00 GMT+2) [2]. This epidemic is attacking 215 countries and regions around the world, such as USA, Spain, Italy, the United Kingdom, Russian Federation, Germany, Brazil, France, Turkey, Iran, Canada, Peru, India, Belgium, Netherlands, Republic of Korea and so on.

people of all ages are susceptible to the novel coronavirus infection [3,4]. Generally, after up to 14-day incubation period [5], most infectious individuals display mild symptoms [6] associated with respiratory illness [5] such as fever, dry cough, fatigue and productive cough, headache, diarrhea, myalgia [6-11], while about 16% of infectious individuals may develop severe symptoms including shortness of breath, chest pain [12]. The case fatality rate was 3.7% worldwide [8], and no specific medicine takes effect until now [13, 14]. The existing evidences suggest that the main transmission of COVID-19 route is via respiratory droplets in an unprotected state and contacting closely with the infected person [13]. Many studies [15-17] revealed that infected individuals in incubation period may be infectious, which greatly increases the difficulty of prevention and control.

To prevent the virus from spreading, the Chinese government put up the “lockdown” measure in Wuhan on 23 January 2020, which was a new approach curbing infectious diseases [3]. Other countries have followed suit. “Lockdown’’ means home quarantine, sealing off the city from all outside for the interruption of the disease transmission. So the schools and businesses are closed, the public should observe home quarantine, keep social distance, stop gathering together and even must insist on wear a mask when they go out for essential activities during the lockdown period [4,5].

Many studies estimated the basic reproduction number in the early phase of COVID-19 outbreak [15-33]. Some results indicated that the basic reproduction number was greater than 3, Tang et al. (6.47 (95%CI: 5.71-7.23)) [15], Shen et al., (4.71 (95%CI: 4.50-4.92)) [16] and Jia et al. (5.6870 inside Hubei, 6.0295 outside Hubei) [17], Zhao et al. (3.58 (95%CI: 2.89-4.39)) [18], Imai (1.5-3.5) [19], Read et al. (3.11 (95%CI: 2.39-4.13)) [20], Cao (4.08) [21], Abbott et al. (2.8-3.8) [22], Bedfordet et al. (1.8-3.5) [23], Chen et al. (2.30 from reservoir to person and 3.58 from person to person) [24] and Huang et al. (3.04-4.35) [25]. More research results argued that the basic reproduction number was less than 3, such as Liu et al. (2.92 (95%CI: 2.28-3.67)) [26], Li et al. (2.2 (95%CI: 1.4-3.9)) [27], Riou (2.2) [28], Majumder et al. (2.55) [29], Tang et al. (1.48-1.69 in Xi’an) [30], Zhang et al. (2.28 (95%CI: 2.06-2.52)) [31], Du et al. 1.32 (95% CI 1.16-1.48) [32] and so on. In fact, the basic reproduction number is closely related to time and region, thus depending on the severity of the epidemic.

In this contribution we developed an SEIQR (susceptible-exposed-infected but not hospitalized-infectious and isolated-recovered) epidemic model to capture the transmission dynamics of COVID-19. In details, based on the cumulative case data and permanent population data of 22 countries or cities, considering the time of lockdown and lifting the lockdown, and with the help of the global optimization algorithm, the parameters of the model were obtained, then the actual confirmed case data were fitted. Further, we considered the trend and scale of the epidemic if the countries or cities were not in lockdown. Our results showed that lockdown measures significantly reduced the number of confirmed cases. In 22 countries or cities, before the lockdown, the basic reproduction numbers were between 1.3884-4.1926; after the lockdown, the basic reproduction numbers were between 1.2141-3.7829; the average basic reproduction numbers were between 1.5286-3.8067. The number of basic reproduction numbers in all countries or cities had decreased sharply after lockdown. Although the epidemic has not been fundamentally controlled for a short time after lockdown in Russia Federation, Spain, Italy, France, Germany, the United Kingdom, Singapore, the United States of New York and the United States of New Jersey owing to their high severity of the epidemics, lockdown remains an extremely effective control strategy that significantly reduces the number of patients and the harmfulness of the pandemic.

2 Methods

2.1 Data

This study simulated the cumulative numbers of cases in 22 countries or cities, which were collected and sorted out from four official reports: (1) WHO (World Health Organization) [2] reports the total confirmed COVID-19 daily new cases worldwide, so the data of the 16 countries was available, including Australia, Belgium, Canada, Denmark, Egypt, France, Germany, India, Norway, Republic of Korea, Russian Federation, Singapore, South Africa, Spain, Switzerland and the United Kingdom. (2) The COVID Tracking Project [33] gave the confirmed COVID-19 daily in 56 states of the United States, and we collected the data of 4 cities of the United States, i.e., California, Illinois, New Jersey and New York. (3) The National Health Commission of the People's Republic of China (NHC) [34] releases daily reports on cumulative confirmed cases of COVID-19 (Nucleic acid test result is positive) of Wuhan City, Hubei Province every day. (4) The Department of Health of Italy [35] reports the daily total case number. The data of Wuhan city that we select isn't over until 1 March 2020 (24:00 GMT+8) while the data of other countries and cities isn't over until 19 April 2020 (10:00 GMT+2). The population data of 22 countries or cities researched above are from World Population in 2020 [36] .

Lockdown suppressed the epidemic in the countries with serious epidemics. As we all know, Wuhan, China is the first city to adopt the strict lockdown measures, followed by other cities in China. It was worth mentioning that South Korea adopted a similar lockdown approach, although South Korea failed to implement strict measures to lockdown the city, such as Daegu and Gyeongsangbuk-do, which were seriously affected by the epidemic. The time of lockdown, time of remove the lockdown and the specific measures of lockdown in 22 countries or cities were listed in Supplementary Materials (see Table 3 for details).

2.2 The COVID-19 Model

In what follows, the impact of lockdown on the COVID-19 epidemics in the 22 countries or cities was investigated by formulating an SEIQR epidemic model. The total population related to COVID-19, N, was divided into 5 epidemiological subgroups: susceptible, S; exposed, E; infectious but not hospitalized (maybe quarantine at home), I; infectious and isolated Q and recovered, R individuals, thus $N=S+E+I+Q+R$. Meanwhile, ``$M$ " represents the number of the cumulative infectious and isolated individuals, ``C " denotes the number of the individuals who are identified not to be patients with COVID-19 and removed from the system. Note that the suspected cases during the COVID-19 pandemic may be influenza patients from current influenza season since their symptoms are similar to those of COVID-19 patients. Consequently, the following modelling assumptions were made based on some biological significance:

(1) Natural birth and death were ignored since we focused on the short-term transmission dynamics;

(2) The individuals in incubation period have the potential to transmit the virus. In addition, infectious and quarantined individuals Q still also have a certain probability to transmit the virus to medical workers. Therefore, the exposed (E) and the infectious and quarantined (Q) were considered infectious, with infectivity reduction factors p and q, respectively;

(4) It was assumed that the transmission rate (β) will decrease and the proportion of confirmed cases ($1-\rho$) will increase after the lockdown. It was realistic to suppose that more people stay in a safer isolation place on the lockdown day, resulting in a decrease in the number of susceptible people.

These considerations above yielded the schematic flow diagram illustrating the transmission dynamics of the COVID-19 in Fig 1, and then the model was described by the following system of ordinary differential equations:

$$
\begin{cases}
\frac{dS}{dt} = -\frac{\beta_1 S(pE + I + qQ)}{N} \\
\frac{dE}{dt} = \frac{\beta_1 S(pE + I + qQ)}{N} - \alpha E, \\
\frac{dI}{dt} = \alpha\rho E - (\omega + \sigma) I, \\
\frac{dQ}{dt} = \alpha(1-\rho)E + \omega I - (\gamma + d)Q, \\
\frac{dR}{dt} = \gamma Q, \\
\frac{dM}{dt} = \alpha(1-\rho)E + \omega I.
\end{cases}
\tag{1}
$$

The biological meanings and acceptable ranges of all parameters of model (1) were demonstrated in Table 1. The basic reproduction number (R_0) represents the number of infected during the initial patient's infectious (not sick) period. This threshold value may determine whether a disease will die out (if $R_0 < 1$) or become epidemic (if $R_0 > 1$). As far as the epidemic models with complex dynamics, $R_0 < 1$ is not only the condition guaranteeing that the disease is extinct, but also the smaller the better. Following Van den Driessche and Watmough [37], we computed the basic reproduction number by COVID-19 as R_0, where

$$
\begin{aligned}
R_0 = & \frac{\beta_1 p}{\underbrace{\alpha}_{\text{contact with exposed class}}} + \frac{\beta_1 \rho}{\underbrace{\omega + \sigma}_{\text{contact with infected class}}} + \underbrace{\frac{\beta_1 q\left(\rho\omega + (\omega+\sigma)(1-\rho)\right)}{(\omega+\sigma)(\gamma+d)}}_{\text{contact with quarantined class}} \\
:= & R_{01} + R_{02} + R_{03}.
\end{aligned}
$$

Here, R_{01}, R_{02} and R_{03} represent the average numbers of the infected individuals by a single exposed individual E, infectious but not hospitalized individual I or infectious and quarantined individual Q in a fully susceptible population, respectively. This also suggests that three transmission ways of COVID-19 contribute to the basic reproduction number R_0.

3 Parameter Estimation

The average incubation period ($1/\alpha$) of COVID-19 is 5.1 days [4], so transition rate of exposed individuals E read $\alpha=0.1961$. We consulted the values of p=0.1 and q=0.38 by Chowell et al. [38], disease-induced death rate $d=1.7826\times10^{-5}$ from Tang et al. [15], then the appropriate range of p, q, and d could be obtained. Considering that the disease course ($1/\delta$) is more than 10 days, and the time requiring to detect a suspected patient ($1/\omega$) is 5 to 15 days, we thus determined the ranges of parameters δ and γ, respectively. The lower and upper limits of other parameters and initial values of model (1) were shown in Table 1. By application of model (1), we fitted the numbers of the cumulative confirmed cases ($M(t)$) to estimate the parameters and initial values through calculating the objective function as follows [39, 40]

$$\min\sum\frac{\left(M(t_i)-\hat{M}(t_i)\right)^2}{\hat{M}(t_i)}$$

with the MATLAB (the Mathworks, Inc.) global optimization tool GlobalSearch. Here, $M(t_i)$ represent the numbers of the cumulative confirmed cases on day i. $\hat{M}(t_i)$ stand for the corresponding fitting values. The simulated parameter values for the 22 countries and cities were shown in Supplementary Materials (Table 4).

4 Results and Discussion

Fig. 2 (a)-(v) shows the fitting results of the 22 countries or cities after lockdown. Meanwhile, the trends of the cumulative number of confirmed cases without lockdown measures were also demonstrated. Judging from the results, lockdown measures in almost countries or cities dramatically reduced the number of confirmed cases, in addition to that Singapore's lockdown measures had no obvious effect on the epidemic control (Fig. 2 (r)). Accordingly, this revealed that a series of strict lockdown measures, for example, locking down cities, restrict access control, suspension from school, home quarantine, canceling social gathering activities, etc., indeed brought about a positive effect on the control of the COVID-19 epidemics.

Based on the simulated parameters, we calculated the basic reproduction numbers before lockdown ($R_0^{(1)}$) and after lockdown ($R_0^{(2)}$) for the 22 countries and cities. Supposed that t_1 was the number of confirmed cases on the first day when the simulation started in a certain country (or city), and t_* was the time of the lockdown. Then the basic reproduction number in the average sense could be defined as $\overline{R}_0 = \dfrac{R_0^{(1)} \times (t_* - t_1) + R_0^{(2)} \times (t_N - t_* + 1)}{t_N - t_1 + 1}$. Detailed results could be found in the second, third and fourth columns of Table 2.

At the same time, we defined the growth ratio of cumulative confirmed cases before the lockdown, $\Delta_j = \dfrac{M(t_*^j - 1) - M(t_*^j - 5)}{M(t_*^j - 5)}$, where $M(t_*^j - 1)$, $M(t_*^j - 5)$ indicated the cumulative number of confirmed cases on the day before locking down the country (or city) *j* and on the fourth day before locking down the country (or city) *j*, respectively. Detailed results were listed in the last column of Table 2.

In the 22 countries or cities, before the lockdown, the basic reproduction numbers were between 1.3884-4.1926; after the lockdown, the basic reproduction numbers were between 1.2141-3.7829; the average basic reproduction numbers were between 1.5286-3.8067. The results were in good agreement with many existing results [18-32]. The basic reproduction numbers in the 22 countries or cities decreased significantly after the lockdown, which suggested that lockdown measures indeed suppressed the epidemics. The basic reproduction numbers after the lockdown were greater than 1, so the epidemic were not fundamentally controlled for a short time after the lockdown (except for Wuhan until 1 March 2020 and other countries or cities until 19 April 2020). At the same time, we also calculated the growth ratio of confirmed cases in the five days before lockdown. This value intuitively reflects the increase rate in cases before the lockdown. Judging from the values of basic reproduction numbers, Russia Federation, Spain, Italy, France, Germany, the United Kingdom, Singapore, New York and New Jersey were very severely affected areas. This conclusion was also consistent with the case data reported by WHO [2]. Combining basic reproduction numbers, lockdown time and case growth ratio, Denmark, Egypt and Singapore adopted lockdown measures earlier when the outbreaks were relatively less severe.

5 Conclusion

According to the epidemiological characteristics of COVID-19, an SEIQR model was established. Considering the lockdown time and the number of confirmed cases in 22 countries or cities, we simulated the epidemiological parameters of each country or city, and made a detailed comparative analysis on whether to implement the lockdown measures (as shown in Fig. 2). A significant reduction in basic reproduction number (as shown in Table 2) and the number of cases reported by 22 countries or cities is significantly lower than that without lockdown measures (Fig. 2) show that lockdown is an extremely effective control measure.

Currently, COVID-19 still has been rampant around the world, threatening people's health and affecting people's normal lives. Many countries and territories have been carrying out strict measures to lock down the cities and even country. Obviously, timely lockdown could limit the epidemics to the smaller areas and avoid large-scale outbreaks, and thus lockdown is such an extremely effective control measure that can significantly reduce the number of patients and the harmfulness of the epidemic. In the face of the persistent spread of the epidemic, it is necessary for us to consider the measures of lockdown the city in time, which also brings inspiration for similar sudden infectious diseases in the future.

Abbreviations

COVID-19: Novel coronavirus disease; WHO: World Health Organization; NHC: National Health Commission; GMT: Greenwich Mean Time; SEIQR: Susceptible-exposed-infected but not hospitalized-infectious and isolated-recovered;

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Availability of data and materials

All data are publicly available.

Ethics approval and consent to participate

Since no individual patient's data was collected, the ethical approval or individual consent was not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that there is no conflict of interests regarding the publication of this article. No authors have potential conflicts of interest with reference to this work.

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Table Captions

Table 1 -Parameter definition for COVID-19 model (1).

Table 2 -The basic reproduction numbers and growth ratios of cumulative confirmed cases.

Figure Captions

Figure 1 - Flow chart of compartments of the COVID-19 SEIQR model.

Figure 2 - The comparison between cumulative confirmed cases and the fitting results in 22 countries and cities.

Table 1. Parameter definition for COVID-19 model (1).

Parameter and intervals	Definition	Source
$\beta \in [0.01, 10]$	Transmission rate	Estimated
α	Transition rate of exposed	[4]
$\gamma \in [0.01, 10]$	Recovery rate	Estimated
$\omega \in [0.0667, 0.2]$	Detection rate	Estimated
$p \in [0.1, 0.5]$	Infectivity reduction factors	Estimated
$q \in [0.1, 0.5]$	Infectivity reduction factors	Estimated
$\rho \in [0.1, 1]$	Proportion of the infectious	Estimated

$\sigma \in [0.001, 0.5]$	Removal rate	Estimated
$d \in [0.0001, 0.05]$	Disease-induced death rate	Estimated

Table 2 The basic reproduction numbers and growth ratios of cumulative confirmed cases.

	$R_0^{(1)}$ (Before Lockdown)	$R_0^{(2)}$ (After Lockdown)	Average $\overline{R}_0$	Growth ratio Δ
Australia	4.0336	1.2201	1.8532	1.0482
Belgium	4.1926	1.5326	2.1976	2.4554
California, America	2.3109	1.2227	1.5191	1.4246
Canada	2.5957	1.5197	1.8111	1.6237
Denmark	1.3884	1.2241	1.2561	0.4243
Egypt	2.8205	1.2320	1.6384	0.7849
France	3.1366	2.4195	2.6490	1.3711
Germany	3.9865	1.2143	2.3786	1.9993
Illinois, America	3.9761	1.3158	1.8059	5.5938
India	2.7518	1.2219	1.6471	1.2256
Italy	3.7270	2.7392	3.0038	1.3875
New Jersey, American	3.3610	2.4150	2.5940	4.0000
New York, America	3.9682	3.0673	3.3187	4.6955
Norway	3.9850	1.4671	2.4399	1.4513
Republic of Korea	3.6281	1.2234	1.5286	7.0096
Russian Federation	3.9190	3.7829	3.8067	1.7353
Singapore	3.6653	1.5866	2.5012	0.4607

South Africa	3.9743	1.3025	2.1690	1.7024
Spain	4.1572	2.6451	3.0154	4.0340
Switzerland	3.9784	1.2231	1.9259	2.4109
The United Kingdom	3.0901	1.5332	2.2182	1.5681
Wuhan, China	3.0118	1.9860	2.1606	2.5124

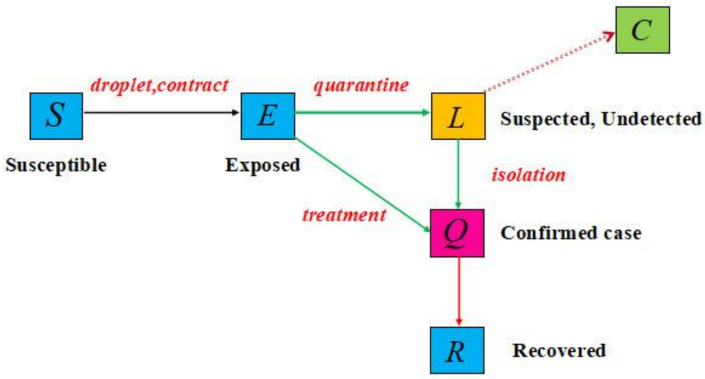
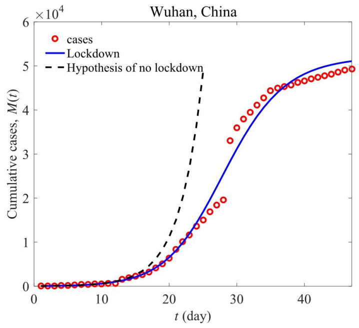
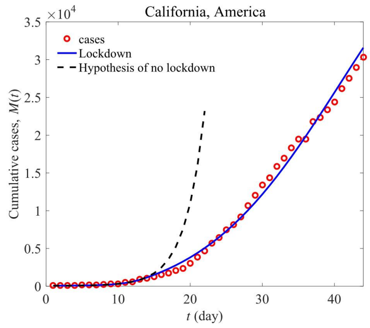


Fig1. Flow chart of compartments of the COVID-19 SEIQR model.



(a)



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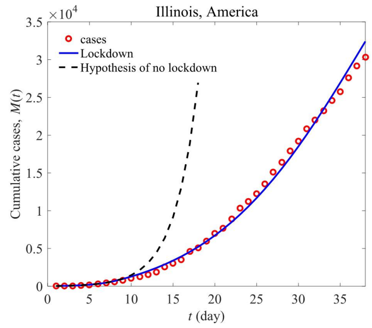

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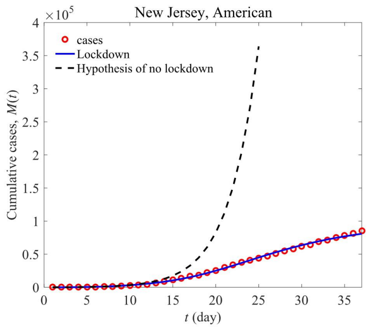

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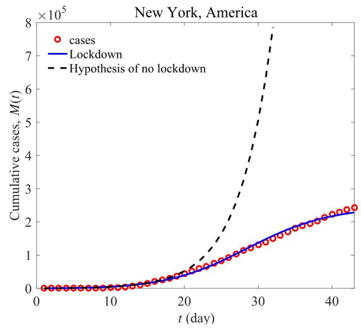

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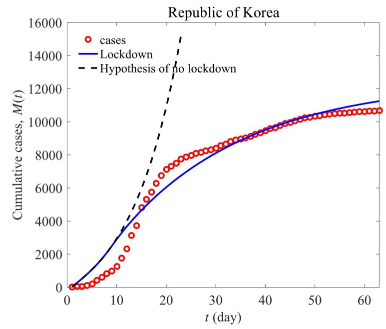

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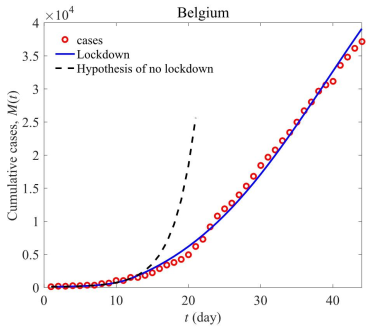

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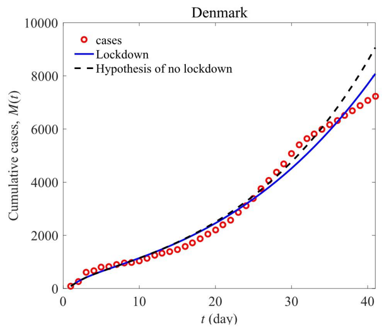

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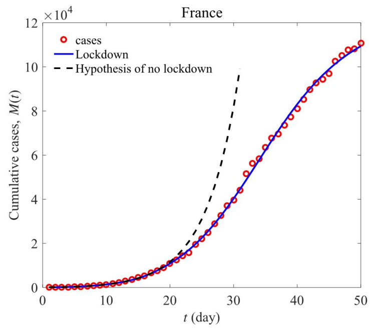
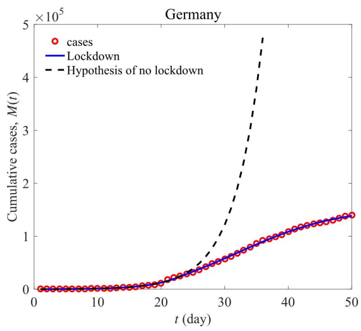


(i)



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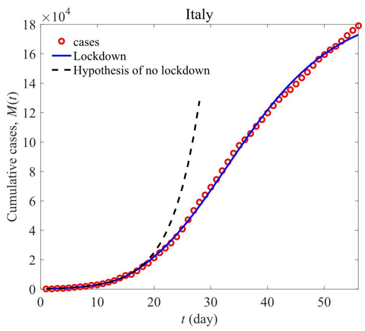
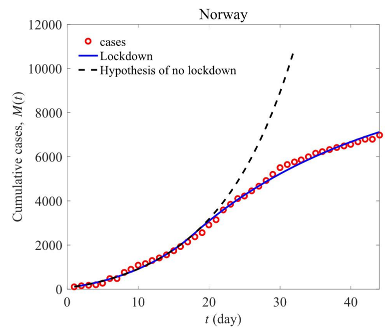


(k)



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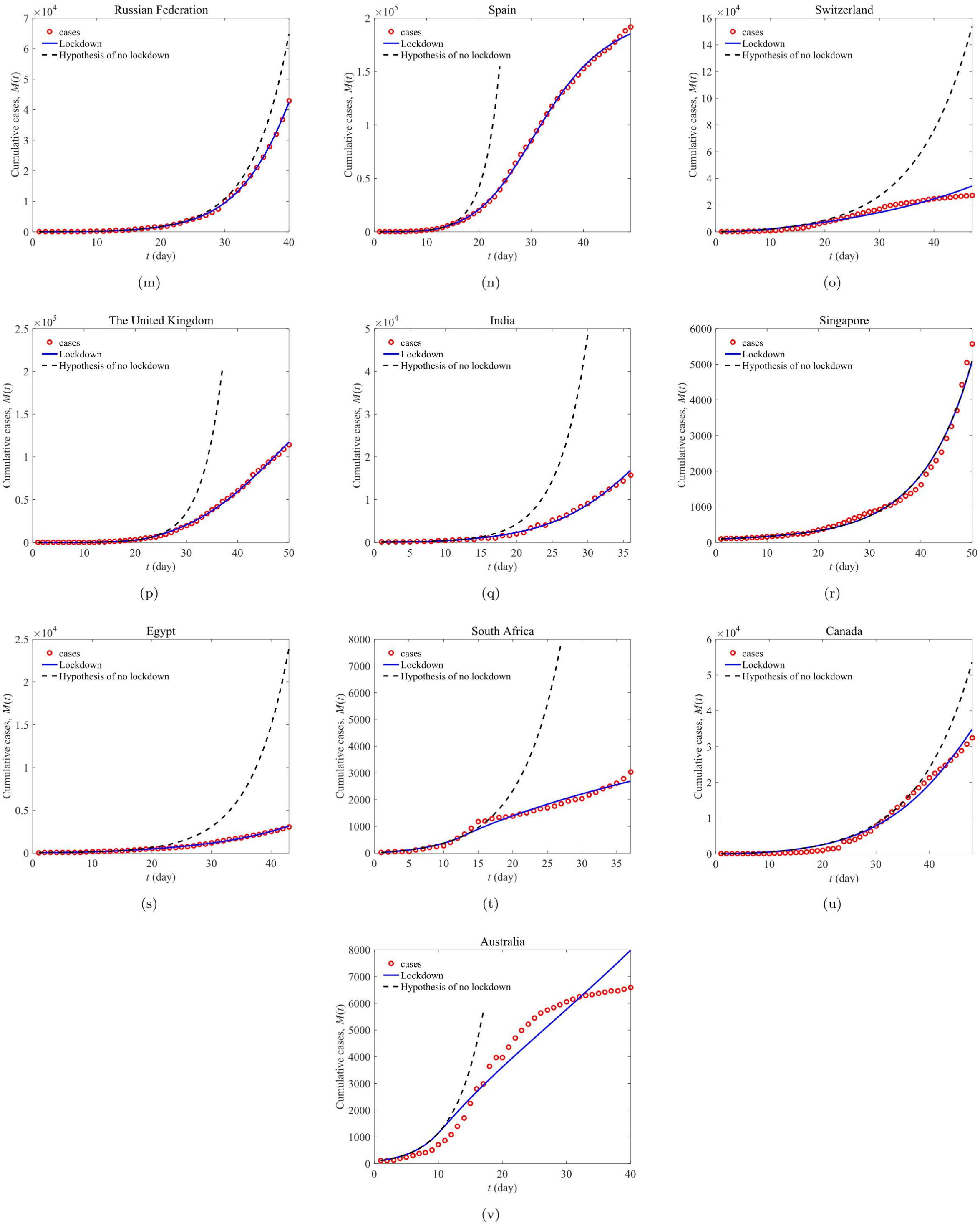

Figure 2: The comparison between cumulative confirmed cases and the fitting results in 22 countries and cities.

Supplementary Materials:

Table 3. Overview on lockdown for the COVID-19 pandemic in the 22 countries or cities.

Countries and cities	Specific measures	State data	End data
Australia	Australian refused the non-residents entering the country on 20 March. The government put forward social distancing measures on 21 March. ‘‘Non-essential” services were closed which covering people get together in the taverns or hostelries.	2020-03-20, [41]	
Belgium	The National Security Council determined to take actions to response to the COVID-19 epidemic on 17 March. Some measures about social distancing were taken on 18 March until 5 April. ‘‘Non-essential” things like travel, gathering were banned.	2020-03-18, [42]	2020-04-19, [43]
California, America	Sacramento County demanded residents to stay at home on 19 March. The instruction was upgraded to official order with legal results.	2020-03-19, [44]	2020-05-15, [45]
Canada	Provinces and cities in Canada closed the school, daycare and unimportant businesses. Gatherings were banned. Entrance and border access were restricted. All newly returned travelers must quarantine themselves for two weeks by the federal Minister of Health.	2020-03-16, [46]	
Denmark	Some further active restrictions appeared at 10:00 on 18 March. No more than ten people are allowed to be together. Restaurants did not permitted eat-in. The other shops in business should provide enough space to prevent close contact.	2020-03-18, [47]	
Egypt	The Egyptian government decided to take measures to restrict resident’s activity from 19 to 31 March 2020, namely, all public areas all over the country were closed including restaurants, cafes and nightclubs from 7p.m. to 6a.m. the next day.	2020-03-19, [48]	
France	All the ‘‘Non-essential” places in public weren’t allowed to open at midnight under the prime minister’s order which obtain cinemas, restaurants, nightclubs and restaurants.	2020-03-17, [49]	2020-05-11, [50]
Germany	The government issued a nationwide curfew to keep residents staying at home except some certain activities. People could hitchhike to work. They were able to exercise themselves and made purchases. However more than two people were not allowed unless they came from the same family.	2020-03-23, [51]	2020-05-03, [52]
Illinois, America	Measures were taken to control the virus’s spread by the	2020-03-20,	2020-05-30,

	method of closing schools, asking the restaurants and bars to provide packaged food, ordering a stop to eviction enforcements. People's gatherings were restricted.	[53]	[54]
India	Modi declared that the country will implement lockdown policy which lasts 21 days on 24 March 2020. About 1.4 billion people's movement would be influenced.	2020-03-25, [55]	2020-05-03, [56]
Italy	In Italy, the whole events on sports would be banned until at least to April 3rd according to the government's announcement. Conte gave an announcement that previous lockdown measures were extended from "red zones" to the whole country in the evening which leading about 60 million people couldn't go out the country. And he signed the new executive order in official recognition later.	2020-03-09, [57]	2020-05-03, [58]
New Jersey, American	Governorn Murphy made an announcement which asks all state residents to stay at home that the whole non-essential businesses would face the closure by 9p.m. on 21 March.	2020-03-21, [59]	
New York, America	Blasio appealed to have a shelter-in-place model like California on 20 March. Cuomo declared that people should stay at home.	2020-03-20, [60]	2020-05-15, [61]
Norway	The lockdown measures were put forward and would take effect at 6p.m. on 12 March. Everything related to gatherings would be banned to open or cancelled, like schools, centers, restaurants, cultural events, sports and so on.	2020-03-12, [62]	2020-04-13, [62]
Republic of Korea	Korean government took measures to protect nationals like sealing off the city to the maximum extend to control the outbreak in Daegu and Gyeongsangbuk-do.	2020-02-25, [63]	
Russian Federation	The government took actions to slow down the rate of infection. Events were abolished. Entertainment venues like theaters were closed. Borders were shut. And there was a declared non-working period appeared till 30 April.	2020-03-18, [64]	2020-05-01, [64]
Singapore	All travellers whether or not local residents came to Singapore must submit health claim online before going through immigration at 9a.m. from 27 March under the Immigration and Checkpoints Authority's announcement.	2020-03-27, [65]	2020-06-01, [66]
South Africa	No gatherings except funerals such as restaurants, hotels, bars were allowed in the lockdown period. Only shops that selling essential goods were permitted to open.	2020-03-26, [67]	2020-04-30, [68]
Spain	Some compulsive lockdown requirements were carried out including only people who are going to buy food or medicines and that need to work or attend pressing matter can leave their home, non-essential businesses like cinemas and retail will be closed.	2020-03-14, [69]	2020-05-09, [70]
Switzerland	Further measures were put forward by the Immigration and Checkpoints Authority which asked the gathering public	2020-03-17, [71]	

	places including shops and bars to close until 19 April on 16 March 2020. A number of essential businesses obtaining postal service, drugstore, goods store and public transport could able to operate to leave.		
The United Kingdom	Lockdown measures were imposed by the government on everyone on 23 March. People contacting with others could only in their home and they couldn't go outside because of "Non-essential" travel and almost everywhere were ordered to shut down, such as venues, places to pray and facilities.	2020-03-23, [72]	
Wuhan, China	The city's bus, subway, ferry, long-distance passenger transport suspended operations since 10a.m. on 23 January. Citizens were not allowed to leave Wuhan except for special reasons. Airports and train stations were temporarily closed.	2020-01-23, [73]	2020-04-08, [74]

Table 4. Parameter values of 22 countries or regions (Before lockdown, β_1 and ρ_1 ;after lockdown, β_2 and ρ_2 .

Parameters	Australia	Belgium	California, America	Canada	Denmark
S(0)	25550560	11527642	39770000	37625816	5835857
E(0)	189.5838328	25.43058263	14.54874443	10	11.35749731
I(0)	23.17552933	22.81366263	1.914129114	148.7127856	422.4645119
Q(0)	0.09185999	24.90225402	20.72589173	1.94E-08	0.014624127
R(0)	3.811730397	64.76607357	20.01668138	11.82201047	1.089858989
M(0)	112	109	69	27	90
D(0)	1.51E-07	6.769032727	1.245035813	3.779649521	0.947282383
S(t*)	8507625.774	100000	100007.4313	122706.1409	100001.3415
α	0.196078431	0.196078431	0.196078431	0.196078431	0.196078431
β_1	1.289765911	1.312948649	1.421683387	0.263786969	0.332458549
d	0.043246949	0.162404836	0.199992157	0.168530171	0.097456422
γ	0.08661704	0.001220649	0.099996243	0.000181546	0.068271145
σ	0.5	0.327293962	0.455763901	0.002235696	0.5
ω	0.155488683	0.214998226	0.290682687	0.131829023	0.089769315
p	0.100229888	0.122351347	0.100000001	0.999762174	0.709030711
q	0.499999971	0.43550978	0.34108774	0.105268901	0.129793802
ρ_1	0.796198777	0.177812866	0.13703614	0.700405148	0.539672402
β_2	0.298922985	0.48275261	0.606135774	0.259222559	0.309114573
ρ_2	0.120006991	0.100000093	0.742751189	0.1664294	0.33019475

Parameters	Egypt	France	Germany	Illinois, America	India
S(0)	101967503	67399310	82702105	12760000	1377446025
E(0)	10.11041698	10	11.49124314	81.8980581	12.34110474
I(0)	18.32423686	192.7214487	177.0652049	19.09496945	58.3457049
Q(0)	0.861644153	0.129356007	0.973561193	468.2077641	59.88767567
R(0)	1.053005122	1.201275415	1.032121023	12.91430401	2.129158181
M(0)	48	100	57	32	107
D(0)	1.68357781	5.52E-16	0.029537237	0.211615631	0.109626578
S(t*)	100000.1454	149758.7573	131328.2821	100000.0009	100000

α	0.196078431	0.196078431	0.196078431	0.196078431	0.196078431
β_1	0.528847074	0.770897977	0.491258426	0.989998109	0.467044727
d	0.089062905	0.048715398	1.03E-06	0.098220028	0.16538333
γ	0.029399084	0.054148964	0.067257567	0.078261458	0.099443091
σ	0.197103162	0.018216319	0.078617011	0.262390085	0.001000001
ω	0.183465965	0.147024386	0.338708863	0.317732124	0.319623848
p	0.26845327	0.100000962	0.66769323	0.27980713	0.686507341
q	0.499326727	0.314322985	0.296828248	0.5	0.499920758
ρ_1	0.1	0.107267162	0.658768906	0.144349768	0.404168782
β_2	0.230952498	0.600789228	0.161823355	0.324205485	0.216601104
ρ_2	0.102498812	0.100000105	0.268303473	0.240315407	0.324159222

Parameters	Italy	New Jersey, American	New York,America	Norway	Republic of Korea
S(0)	60266946	9030000	19795791	5412020	82012000
E(0)	632.0539373	10.25900543	603.7223509	107.2351786	1242.16368
I(0)	13.25841926	270.7858179	294.4368834	57.76218031	3.155437977
Q(0)	1.95E-05	45.88232527	3.47E-09	448.1175846	1.178771074
R(0)	416.7113522	3.102344953	1.121272002	2.630441637	94.66707165
M(0)	229	50	105	113	31
D(0)	0.016495808	0.754341253	1.89E-09	0.602191265	0.033708319
S(t*)	243180.418	107144.3889	265134.6242	4919125.968	5444047.079
α	0.196078431	0.196078431	0.196078431	0.196078431	0.196078431
β_1	0.904704016	0.5877485539	0.62399461	1.608175383	1.703029345
d	0.097290077	0.050473046	1.03E-06	0.199995328	0.190827174
γ	0.013878196	0.014511961	0.063260489	0.049768744	0.069654076
σ	0.5	0.049117063	0.001	0.351141107	0.307900843
ω	0.23322937	0.495010283	0.277020079	0.08862127	0.0667
p	0.118290686	0.1	0.835615797	0.1	0.153642482
q	0.471707049	0.3078318814	0.145879111	0.183382671	0.197480262
ρ_1	0.390133043	0.412300333	0.198116841	0.796199909	0.370267213
β_2	0.634522184	0.413478856	0.468103023	0.658773352	0.573050205

ρ_2	0.26113841	0.499017561	0.251944967	0.647491202	0.372256318

Parameters	Russian Federation	Singapore	South Africa	Spain	Switzerland
S(0)	144249683	5760326	59167589	46712506	8629514
E(0)	10.99506585	10.08120629	120.9386912	95.8470612	133.5077666
I(0)	2.147078114	17.63959496	0.875417232	45.13774192	272.4595353
Q(0)	139.8554103	1.98E-09	1.34E-13	0.021367796	0.010081842
R(0)	9.475726343	1.000968492	1.067823551	87.66337792	1.080239941
M(0)	7	102	17	45	37
D(0)	8.13E-14	0.274843222	1.06E-05	0.057053631	1.56E-07
S(t*)	209226.839	3479782.744	117699.8792	217208.7133	4885493.266
α	0.196078431	0.196078431	0.196078431	0.196078431	0.196078431
β_1	0.499468235	0.395022714	1.633652597	1.099860897	0.888408654
d	0.02230606	1.72E-05	0.153188952	0.090320305	0.19999719
γ	0.097763275	0.099663631	0.1	0.029570804	0.045477883
σ	0.227716296	0.05574958	0.225329208	0.133655139	0.170870079
ω	0.132027184	0.070062214	0.0667	0.246977735	0.111175971
p	0.916101898	0.575086266	0.229892324	0.100311196	0.933219169
q	0.5	0.100083776	0.292980405	0.387143839	0.1
ρ_1	0.12270645	0.7962	0.140646173	0.1	0.102431642
β_2	0.478318419	0.391299889	0.31828144	0.646774264	0.270740773
ρ_2	0.557500615	0.1	0.796199999	0.307601971	0.113409041

Parameters	The United Kingdom	Wuhan, China
S(0)	67154714	11006500
E(0)	50.84726368	119.9614909
I(0)	0.55789758	31.88897219
Q(0)	10.64059571	2.120220342
R(0)	1.000381623	79.54822742
M(0)	23	53
D(0)	2.820549883	6.28E-09

S(t*)	292555.0779	100000.3412
α	0.196078431	0.196078431
β_1	0.851205532	0.584902644
d	0.178186469	0.186045425
γ	0.007412915	0.01086337
σ	0.219129133	0.001001504
ω	0.201400814	0.269069912
p	0.201211261	0.324810319
q	0.5	0.5
ρ_1	0.134903393	0.354913022
β_2	0.368944752	0.456826862
ρ_2	0.674257344	0.137787625

Figures

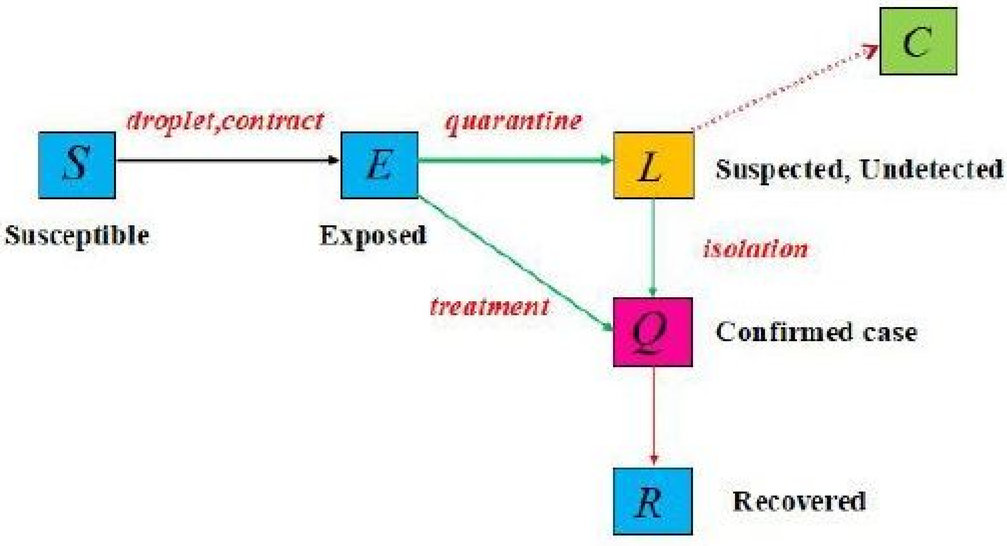

Figure 1

Flow chart of compartments of the COVID-19 SEIQR model.

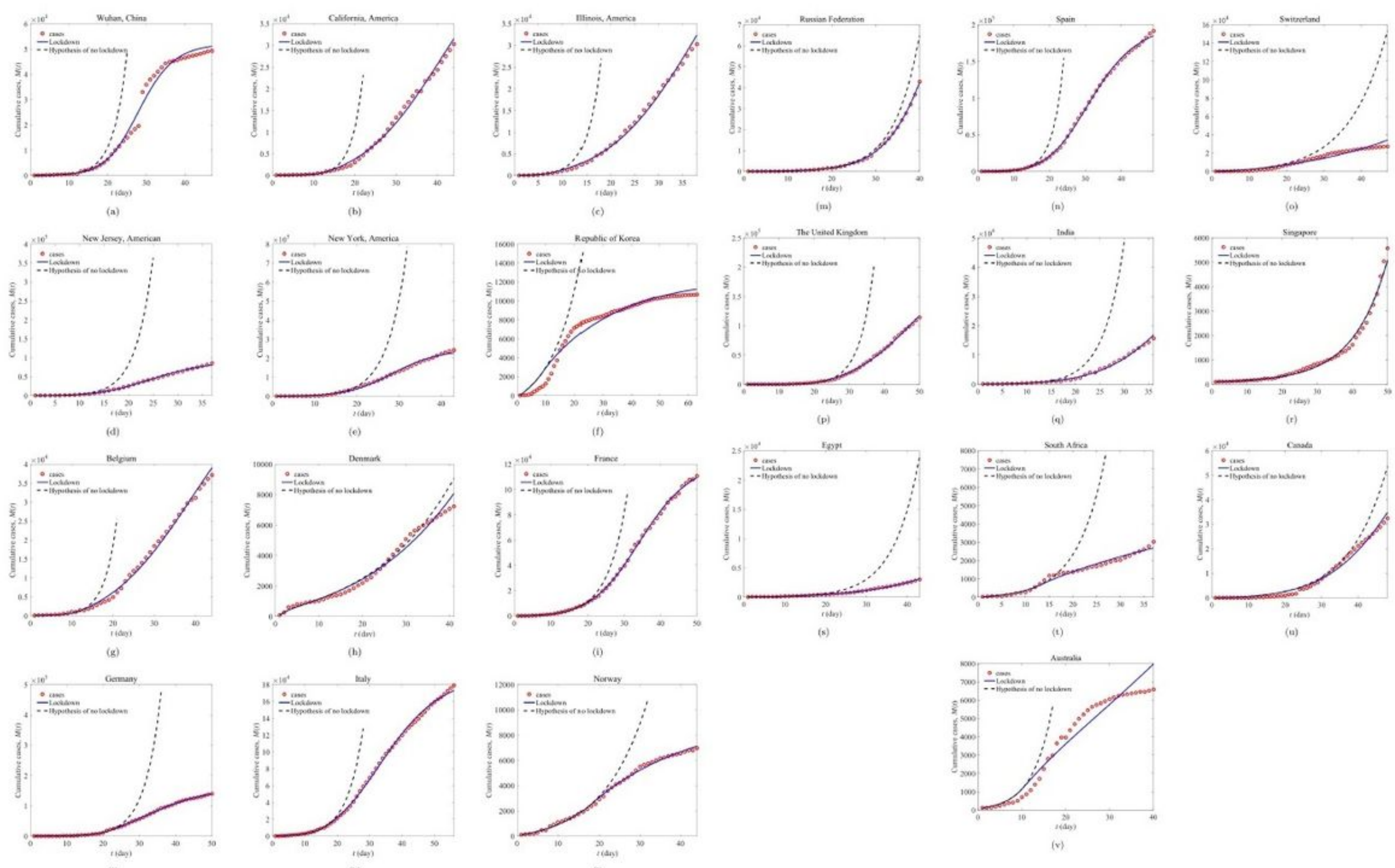

Figure 2

The comparison between cumulative confirmed cases and the fitting results in 22 countries and cities