XINN, Volume ■ ■

Supplemental Information

What Is Required to Prevent a Second Major Outbreak of SARS-CoV-2 upon Lifting Quarantine in Wuhan City, China

Lei Zhang, Mingwang Shen, Xiaomeng Ma, Shu Su, Wenfeng Gong, Jing Wang, Yusha Tao, Zhuoru Zou, Rui Zhao, Joseph T.F. Lau, Wei Li, Feng Liu, Kai Ye, Youfa Wang, Guihua Zhuang, and Christopher K. Fairley

Supplementary Materials:

Method:

Data collection:

We collected the epidemic data, including the number of daily and cumulative confirmed cases and deaths, from 10th January 2020 to 7th March 2020 based on official reports from the Wuhan Municipal Health Commission [1]and the Health Commission of Hubei Province [2] (Table S1). Change of definition for confirmed cases was noted in the data reports. Before treatment guideline version 5 [3] (published on 8th February), all positive cases needed to be confirmed by laboratory tests. This guideline was effective for only 11 days until 18th February. During this period, the definition of confirmed cases was changed to include both laboratory and clinical diagnoses, which resulted in a reverse-addition of over 14000 cases (Figure S3a). The treatment guideline v6 [4] became effective on 19th February, and the definition reversed to include the laboratory-confirmed cases only. However, all previously clinically confirmed cases remained unchanged. We collected clinical, disease progression and behavioural parameters from published literature (Table S2).

Model formulation and assumptions

We constructed a compartmental dynamic model to describe the transmission of COVID-19 in Wuhan city, China. The population was divided into thirteen compartments (Figure S1), including susceptible individuals, asymptomatic infected individuals in the incubation period, undiagnosed infected individuals (with mild, moderate, and severe/critical symptoms), clinically diagnosed cases with radiographic evidence of pneumonia but negative laboratory testing results (with mild, moderate, and severe/critical symptoms), laboratory diagnosed cases (with mild, moderate, and severe/critical symptoms), recovered and death cases. Notably, a key assumption we made is that asymptomatic individual during the incubation period is capable of transmitting the virus [5, 6] (detail assumptions in the Supplementary Materials). We did not consider the potential impact of resumption of intercity travel on the spread of the epidemic to other parts of the country in this model but assumed it would be the same as residual cases remaining in the city.

We modelled three modes of transmission, including contacts in public venues (e.g. public transportations, supermarkets and offices), household and hospitals. The probability of acquisition in each of these venues depends on two modifiable behaviours, the number of person-to-person contacts and facial mask usage. The use of facial mask was able to reduce aerosol transmission of the virus and also transmission via hand-face contacts [7]. The implementation and lifting of the metropolitan-wide quarantine would increase or decrease these behaviours (details in Table S2), hence alter the trajectory of the epidemic. Notably, in hospitals, both non-COVID-19 patients on-site and medical staff were at-risk of infections, and the probability of acquisition of medical staff is higher than on-site patients due to a higher contact rate.

Model calibration

We calibrated the model to the daily and deaths cases by minimising the differences between model simulations and the observed data based on a nonlinear least-squares method (Figure S3). Unknown parameters were sampled within their bounds using the Latin hypercube sampling and repeated 1000 times. We ranked all simulations by the sum of squared errors and selected the top 10% of the least error to generate the 95% confidence intervals of the model outputs. A new set of bounds was generated based on the selected simulations, and the parameters were re-sampled. The iteration was repeated for ten times. The last selected set of results provided the 95% confidence intervals of the model outputs. Our calibration was also adjusted to adapt the temporary changes in the definition of confirmed cases to include both clinically and laboratory diagnosis according to treatment guideline v5 (Figure S3a). All analyses and simulations were performed in MATLAB R 2019a.

Construction of scenarios

We constructed the scenarios for the implementation (initiated on 23rd January 2020) and lifting of the metropolitan-wide quarantine at various dates (21st March, 28th April, 4th April, 11th April, 18th April and 25th April). Theses days are each seven days apart. We assumed that the implementation and lifting would mainly affect person-to-person contacts and the use of a facial mask. Upon implementing the quarantine, the number of public contacts per person-day had significantly reduced by 80% whereas household contacts were tripled. Upon lifting the quarantine, we projected the epidemic at scenarios where the number of public contacts was returned to 50%, 80%, 100% and 150% of the pre-quarantine level and facial mask usage at 95%, 80%, 50% and 10%. We assumed household contacts would return to the pre-quarantine level after lifting the quarantine. In all the scenarios, the numbers of hospital contacts for patients and doctors were set at 20 and 60 per person-day, but they were allowed to decrease in the same rate as the number of diagnosed infected individuals after the peak of the epidemic. We included for completeness' sake the day when all internal cases were likely to have resolved although acknowledge that with intercity travel, this scenario is not a practical option.

Model details

1. Model formulation

We proposed a dynamic compartmental model to describe the transmission of COVID-19 in Wuhan city, Hubei province, China. The population was divided into thirteen compartments (**Figure S1**): susceptible individuals (S), asymptomatic (but infectious) individuals during the incubation period (E), undiagnosed infectious individuals with mild (I_1), moderate (I_2), and severe/critical (I_3) symptoms, clinical diagnosed cases with radiographic evidence of pneumonia, but testing result negative at the mild (D_1), moderate (D_2), and severe/critical (D_3) stage, treated individuals after lab diagnosis at the mild (T_1), moderate (T_2), and severe/critical (T_3) stage, recovered (R) and dead (D) individuals. The total population size was denoted as N, ($N=S+E+I_1+I_2+I_3+D_1+D_2+D_3+T_1+T_2+T_3+R$).

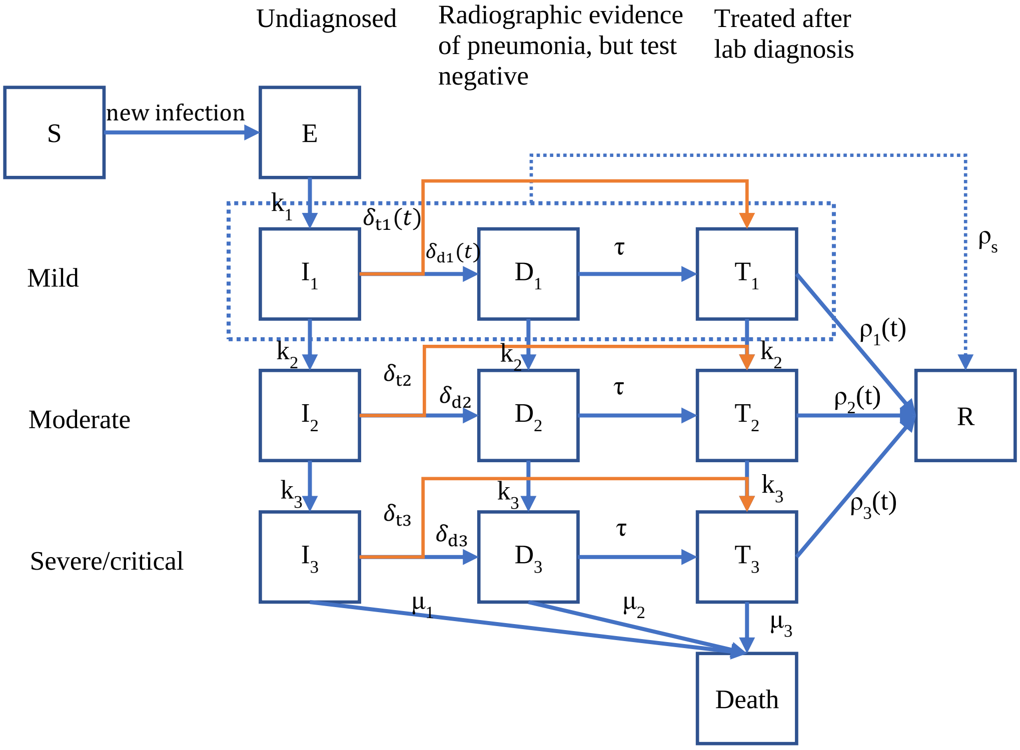

Figure S1. A schematic flow diagram of COVID-19 infection. The recovery rate of clinically diagnosed cases at the mild (D_1), moderate (D_2), and severe/critical (D_3) stage are $\rho_{d1}(t)$, $\rho_{d2}(t)$, $\rho_{d3}(t)$, respectively, and not shown here due to too many arrows.

Susceptible individuals became infected by being in contact with latent (E) and undiagnosed infectious individuals with symptoms (I_1, I_2, I_3) in the public space and household (private space), and in contact with infected individuals (D_1, D_2, D_3, T_1, T_2, T_3) in a hospital setting. The overall rate of infection was given as the sum of rates of infections via these routes. That is,

$$\Lambda_{total} = \Lambda_{pub} + \Lambda_{pri} + \Lambda_{hos\_p} + \Lambda_{hos\_d}$$

, and for each of route of transmission,

(1) public contacts

$$\Lambda_{pub} = \beta_E^{pub}(t)\frac{SE}{N} + \beta_I^{pub}(t)\frac{S\sum_{i=1}^{3} I_i}{N}$$

(2) household contacts

$$\Lambda_{pri} = \beta_E^{pri}(t)\frac{S_f E}{N_f} + \beta_I^{pri}(t)\frac{S_f \sum_{i=1}^{3} I_i}{N_f}$$

(3) non-COVID-19 patients in contact with COVID-19 infected individuals in a hospital setting

$$\Lambda_{hos\_p} = \beta_{Ip}^{hos}(t)\frac{S_p \sum_{i=1}^{3} I_i}{N_p}$$

(4) medical staff in contact with COVID-19 infected individuals in a hospital setting

$$\Lambda_{hos\_d} = \beta_{Id}^{hos}(t)\frac{S_d \sum_{i=1}^{3}(D_i+T_i)}{N_d},$$

where

$$\beta_I^{pub}(t) = \beta m_1(t)(1-\theta_1 p_1(t)), \beta_E^{pub}(t) = (1-\varepsilon)\beta_I^{pub}(t),$$

$$\beta_I^{pri}(t) = \beta m_2(t)(1-\theta_1 p_2), \beta_E^{pri}(t) = (1-\varepsilon)\beta_I^{pri}(t),$$
$$\beta_{Ip}^{hos}(t) = \beta_{hos} m_3(1-\theta_1 p_3), \beta_{Id}^{hos}(t) = \beta_{hos} m_4(1-\theta_2 p_3),$$

of which β denoted the probability of transmission per contact with the infectious individuals with symptoms, and we assumed this probability was lower ($(1-\varepsilon)\beta$, here $0 \leq \varepsilon \leq 1$ denotes the reduction in per-act transmission probability) when in contact with the latent individuals. β_{hos} denoted the probability of transmission per contact in the hospital. $m_1(t)$ and $m_2(t)$ denoted the average number of daily person-to-person contacts in the public space and household, respectively. $p_1(t)$, p_2 and p_3 denoted the usage rate of the mask in the public space, household and hospital, respectively. θ_1 and θ_2 denoted the effectiveness of facial mask/respirators for infection prevention by the general population and medical staff, respectively. m_3 denoted the average daily contacts between patients in a hospital setting. m_4 denoted the average daily contacts between medical staff and COVID-19 infected patients.

Estimation of the population size and number of susceptibles for each route of transmission

For public contacts, the overall population size (N) was the number of residents in Wuhan city, whereas the number of susceptibles was the number of individuals free of COVID-19 infection (S).

For household contacts, the overall population size (N_f) was estimated as the total number of households members that are at-risk of COVID-19 infection, whereas the number of susceptible households members (S_f) is the difference between N_f and the number of infected individuals in these households. We assumed that the number of the households at-risk of infection was same as the number of individuals infected in public space because the probability of two or more household members was infected at the same time but at different public venues was very small. Hence,

$$N_f(t) = rF_1(t),$$

Where r was the average number of household members in a Chinese family and $F_1(t)$ was the cumulative number of individuals infected in public space $F_1(t)$, given by

$$F_1(t) = \int_0^t \left(\beta_E^{pub}(t) \frac{SE}{N} + \beta_I^{pub}(t) \frac{S \sum_{i=1}^{3} I_i}{N} \right) dt.$$

Further, the number of susceptible household members was given as,

$$S_f(t) = (r-1)F_1(t) - F_2(t),$$

where $F_2(t)$ denoted the accumulated number of infected household members through household transmission,

$$F_2(t) = \int_0^t \left(\beta_E^{pri}(t) \frac{S_f E}{N_f} + \beta_I^{pri}(t) \frac{S_f \sum_{i=1}^{3} I_i}{N_f} \right) dt.$$

An illustration of household transmission was presented in **Figure S2.**

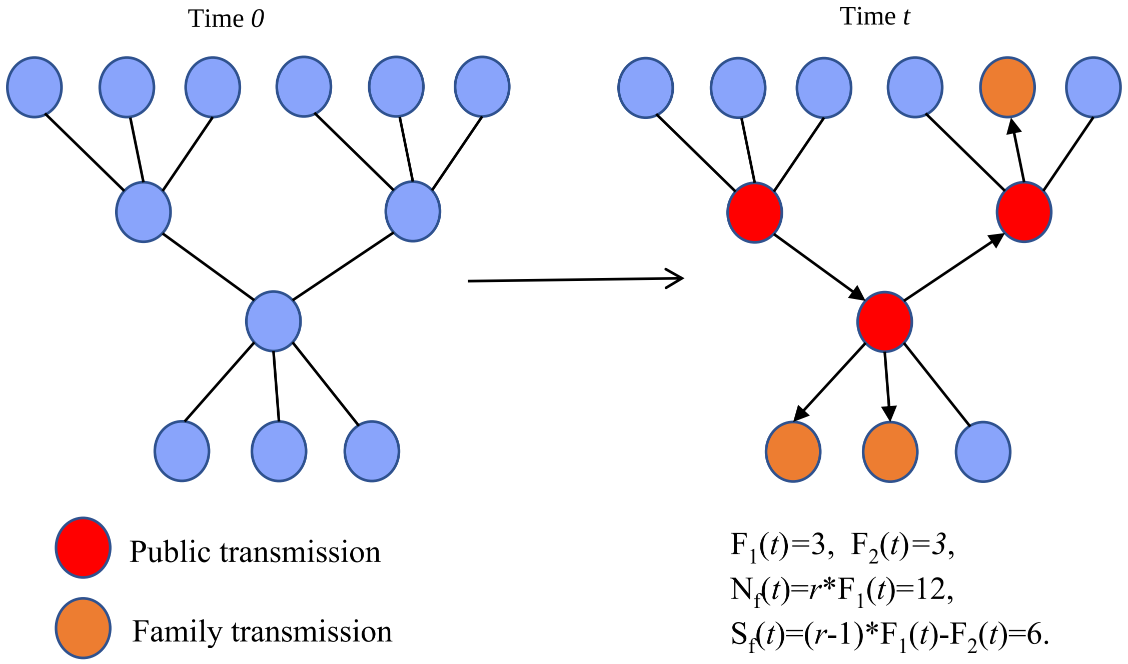

Figure S2. An example about the public and private transmission. The average number of family member r=4.

For hospital contacts, we assumed that individuals who were suspected of infections but not yet being confirmed were most at-risk of hospital-acquired infections. The estimated number of suspected individuals is approximately 100,000 in Wuhan, and the positive diagnosed rate was about 30-40%. Therefore, N_p was approximately 60000-70000 individuals. Similarly, S_p was given as

$$S_p(t) = N_p - F_3(t),$$

where $F_3(t)$ denoted the accumulated number of non-COVID-19 patients infected through hospital contacts,

$$F_3(t) = \int_0^t \beta_{Ip}^{hos}(t)\frac{S_p\sum_{i=1}^{3} I_i}{N_p}dt.$$

Further, for medical staff who were in direct contact with COVID-19 individuals, the overall population size (N_d) was 120,000, accounting for 80,000 medical staff in Wuhan and 40,000 from the rest of the country. Similarly, S_d was given as

$$S_d(t) = N_d - F_4(t),$$

where $F_4(t)$ denoted the accumulated number of medical staff infected through hospital contacts,

$$F_4(t) = \int_0^t \beta_{Id}^{hos}(t)\frac{S_d\sum_{i=1}^{3}(D_i + T_i)}{N_d}dt.$$

Modelling disease progression

Individuals in the incubation period (E) progressed to the infectious compartment (infected but undiagnosed) with mild symptoms at a rate k_1. The progression rates from mild to moderate symptoms and from moderate to severe/critical symptoms were k_2 and k_3, respectively. The detection rates of the infectious compartment with mild, moderate, and severe/critical symptoms by lab diagnosis are $\delta_{t1}(t)$, δ_{t2}, and δ_{t3}, respectively. The detection rates of the infectious compartment with mild, moderate, and severe/critical symptoms by clinical diagnosis were $\delta_{d1}(t)$, δ_{d2}, and δ_{d3}, respectively. τ denoted the detection rate in clinically diagnosed individuals with a previous negative lab test. The death rates of undiagnosed, clinical diagnosed, and lab diagnosed individuals with severe/critical symptoms are μ_1, μ_2, μ_3, respectively. We assumed all diagnosed individuals were isolated but may still be able to transmit the virus to medical staff. Infected individuals with mild symptoms were assumed to recover spontaneously at a rate ρ_s. Lab diagnosed individuals on treatment who were in mild, moderate, and severe/critical stage would recover at the rate $\rho_1(t)$, $\rho_2(t)$, $\rho_3(t)$, respectively. Clinically diagnosed individuals at these three stages would recover at the rates $\rho_{d1}(t)$, $\rho_{d2}(t)$, $\rho_{d3}(t)$, respectively (Figure S1). The model was described by the following system of ordinary differential equations:

$$\begin{cases} \dfrac{dS}{dt} = -\Lambda_{total}, \\ \dfrac{dE}{dt} = \Lambda_{total} - k_1 E, \\ \dfrac{dI_1}{dt} = k_1 E - (k_2 + \delta_{d1}(t) + \delta_{t1}(t) + \rho_s) I_1, \\ \dfrac{dI_2}{dt} = k_2 I_1 - (k_3 + \delta_{d2} + \delta_{t2}) I_2, \\ \dfrac{dI_3}{dt} = k_3 I_2 - (\delta_{d3} + \delta_{t3} + \mu_1) I_3, \\ \dfrac{dD_1}{dt} = \delta_{d1}(t) I_1 - (k_2 + \tau + \rho_s + \rho_{d1}(t)) D_1, \\ \dfrac{dD_2}{dt} = \delta_{d2} I_2 + k_2 D_1 - (k_3 + \tau + \rho_{d2}(t)) D_2, \\ \dfrac{dD_3}{dt} = \delta_{d3} I_3 + k_3 D_2 - (\tau + \rho_{d3}(t) + \mu_2) D_3, \\ \dfrac{dT_1}{dt} = \tau D_1 + \delta_{t1}(t) I_1 - (k_2 + \rho_s + \rho_1(t)) T_1, \\ \dfrac{dT_2}{dt} = \tau D_2 + \delta_{t2} I_2 + k_2 T_1 - (k_3 + \rho_2(t)) T_2, \\ \dfrac{dT_3}{dt} = \tau D_3 + \delta_{t3} I_3 + k_3 T_2 - (\rho_3(t) + \mu_3) T_3, \\ \dfrac{dR}{dt} = \rho_1(t) T_1 + \rho_2(t) T_2 + \rho_3(t) T_3 + \rho_{d1}(t) D_1 + \rho_{d2}(t) D_2 + \rho_{d3}(t) D_3 + \rho_s (I_1 + D_1 + T_1), \\ \dfrac{dD}{dt} = \mu_1 I_3 + \mu_2 D_3 + \mu_3 T_3. \end{cases} \tag{1}$$

The cumulative number of reported diagnosed cases, deaths, and recovered individuals according to treatment guidelines version 1-4 and 6-7 (lab diagnosis) were denoted as C_{diag}^{old}, C_{death}^{old}, C_{rec}^{old}. The cumulative number of reported diagnosed cases, deaths, and recovered individuals according to treatment guidelines version 5 (both lab and clinical diagnoses) were denoted as C_{diag}^{new}, C_{death}^{new}, C_{rec}^{new}, respectively. They were defined by the following equations:

$$\frac{dC_{diag}^{old}}{dt} = \tau(D_1 + D_2 + D_3) + \delta_{t1}(t)I_1 + \delta_{t2}I_2 + \delta_{t3}I_3,$$
$$\frac{dC_{death}^{old}}{dt} = \mu_3 T_3,$$
$$\frac{dC_{rec}^{old}}{dt} = \rho_1(t)T_1 + \rho_2(t)T_2 + \rho_3(t)T_3, \qquad (2)$$

and

$$\frac{dC_{diag}^{new}}{dt} = (\delta_{d1}(t) + \delta_{t1}(t))I_1 + (\delta_{d2} + \delta_{t2})I_2 + (\delta_{d3} + \delta_{t3})I_3,$$
$$\frac{dC_{death}^{new}}{dt} = \mu_2 D_3 + \mu_3 T_3,$$
$$\frac{dC_{rec}^{new}}{dt} = \rho_1(t)T_1 + \rho_2(t)T_2 + \rho_3(t)T_3 + \rho_{d1}(t)D_1 + \rho_{d2}(t)D_2 + \rho_{d3}(t)D_3. \; (3)$$

2. Data sources and parameter estimation

We collected the data on the number of daily and cumulative confirmed cases and deaths from 10th January 2020 to 7th March 2020 from the Wuhan Municipal Health Commission [1] and the Health Commission of Hubei Province [9] (**Table S2**. The mean incubation time for COVID-19 was 5.2 days ($1/k_1$=5.2) [9]. It followed from [11] that the median time from the first symptom to dyspnea was five days (interquartile range [IQR], 1-10) and from the onset of symptoms to ICU admission was ten days (IQR, 6-12) (Table 3). Therefore, we assumed that the meantime from mild to moderate symptoms was five days ($1/k_2$=5), and the meantime from moderate to severe/critical was 10-5=5 days ($1/k_3$=5). The mean time from mild symptoms to spontaneous recovery was ten days ($1/\rho_s$=10) [12]. The mean number of members in a Chinese household was four [13]. It followed from [14] that the probability of transmission per contact with infectious individuals in the general population was β=0.09 (0.0873-0.1057) based on the ratio of the cumulative confirmed cases and the cumulative individuals with close contact. We assumed the probability of transmission per contact β_{hos} in the hospital was only 3% of that in the general population due to strict sterilised environment in the hospital, i.e., $\beta_{hos} = 0.03 \times \beta = 0.0027$. The probability of transmission per contact with latent individuals was assumed to be half ($1-\varepsilon$=0.5 [0.1-0.9]) of that with infectious individuals [12].

The facial mask usage rate in the public space is drastically increased during the epidemic [15][16], and we assumed a logistic growth for this percentage, i.e., $p_1(t) = p_{ini} + \frac{\bar{p}-p_{ini}}{1+\exp(-0.5(t-t_{ini}))}$, where $t_{ini} = 15$ is the time when the metropolitan-wide quanratine (23rd Janurary) initiated but with two days delay, p_{ini} is the background facial masks usage rate in the public space before the epidemic, and $\bar{p}$ is the maximal facial masks usage rate in the public space during the epidemic. An observational survey [17] in the street in Beijing show that only about 10% of people wear the facial mask in routine life in winter, so we assumed $p_{ini} = 10\%$ as the base case facial mask usage in the absence of COVID-19. The data in [15] showed that 97.6% of customers wear the facial mask in the shops in Wuhan city after quarantine (23rd January- 10th February 2020). Another online survey [18] show that 97.3-99.3% of people wear the facial mask in the public space, so we assume $\bar{p} = 97.6\%$ (97.3-99.3%). The usage rate of facial mask in the private space p_2 is set as zero [19], and in the hospital facial mask usage p_3 was set as 100% based on the field data. The effectiveness of mask to prevent infection for the general population θ_1 and for the medical staff θ_2 are chosen as 80% (50-95%) and 95% (90%-

100%) (medical staff was assumed to be better equipped), respectively, based on one meta-analysis against respiratory infections [20] and retrospective study against COVID-19 [21].

The data in [15] show that the number of daily customers has reduced by 71-94% since the quarantine on 23 Jan, so we assume the average number of daily contacts in the public space $m_1(t)$ has reduced by 80% in the base case, with a decreasing logistic function, $m_1(t) = m_{ini} + \frac{0.2m_{ini}-m_{ini}}{1+\exp(-0.3(t-t_{ini}))}$, where m_{ini} is the background daily contact number in the public space before the quarantine and was model-estimated. Home confinement led to three times longer 'stay at home' duration than the pre-quarantine level [13], so we assume the average number of daily contacts in a household increased from 4 to 12, in the form of an increasing logistic function, $m_2(t) = 4 + \frac{12-4}{1+\exp(-0.5(t-t_{ini}))}$. The average number of daily contacts between patients was estimated as 20 (10-30), and a medical staff member would be in contact with an average of 60 (50-120) infected individuals. Both numbers were based on field data. Both numbers were allowed to decrease at the same rate as the number of diagnosed infected individuals after the peak of the epidemic.

The lab diagnosis rate of individuals with severe/critical symptoms (δ_{t3}) and moderate symptoms (δ_{t2}) are chosen as 100% [11][12] and 50% [12], respectively. The lab diagnosis rate of individuals with mild symptoms increases gradually as more health resources became available, and we assumed an increasing logistic function, $\delta_{t1}(t) = 0.05 + \frac{\overline{\delta_{t1}}-0.05}{1+\exp(-0.5(t-t_{ini}))}$. This function indicated that only 5% of the patients with mild symptoms was diagnosed daily initially but this rate increases to a higher value of $\overline{\delta_{t1}}$ (model-estimated) over time. We assumed the clinical diagnosis rates for individuals with mild ($\delta_{d1}(t)$), moderate (δ_{d2}), and severe/critical symptoms (δ_{d3}) were proportional to the lab diagnosis rates with a factor f (model-estimated), i.e., $\delta_{d1}(t) = f \times \delta_{t1}(t)$, $\delta_{d2} = f \times \delta_{t2}$, $\delta_{d3} = f \times \delta_{t3}$.

The recovery rate of treated individuals with severe/critical symptoms $\rho_3(t)$ increased over time as more health resources became available, and we assumed an increasing logistic function, $\rho_3(t) = \frac{\overline{\rho_3}}{1+\exp(-\rho_{3k}(t-t_\rho))}$, where $\overline{\rho_3}$ was the maximal recovery rate during the epidemic, ρ_{3k} was the growth rate of recovery, and t_ρ was the time when the recovery rate is half of the maximal recovery rate. All three parameters were model-estimated. According to the report of the WHO-China Joint Mission on COVID-19 [22], the average recovery period for individuals with mild and severe/critical symptoms were 2 and 4.5 weeks, respectively. Thus, we assumed the average recovery period for individuals with moderate symptoms was the average of the two, which was 3.25 weeks. According to these durations, recovery rate of individuals with a moderate symptom was 1.38 times faster than individuals with a severe/critical symptom, that is $\rho_2(t) = 1.38 \times \rho_3(t)$. Similarly, recovery rate of individuals with a mild symptom was 2.25 times faster than individuals with a severe/critical symptom, that is $\rho_1(t) = 2.25 \times \rho_3(t)$. We assumed the recovery rates of clinically diagnosed individuals with mild ($\rho_{d1}(t)$), moderate ($\rho_{d2}(t)$), and severe/critical symptoms ($\rho_{d3}(t)$) were proportional to the recovery rates of lab diagnosed individuals [23] and denoted this factor as q (model-estimated), i.e., $\rho_{d1}(t) = q \times \rho_1(t)$, $\rho_{d2}(t) = q \times \rho_2(t)$, $\rho_{d3}(t) = q \times \rho_3(t)$.

The total population size in Wuhan city was 11,081,000 based on China Population and Employment Statistics Yearbook in 2019. The initial values of the disease states were given as $I_1(0)$=41, N(0)= 11,081,000, and the initial values of other variables are 0. We left E(0) as a model-estimated parameter.

We calibrated the model to the daily confirmed cases and deaths data from 10th January 2020 to 7th March 2020 by using a nonlinear least-squares method. The unknown parameters

(**Table S1**) were sampled within their bounds by the Latin hypercube sampling method and repeated 1000 times. For every simulation, we calculated the sum of squared errors between the model output and data, and selected the top 10% with the least square errors was selected to form a new dataset. The selected dataset was then used to generate a new set of narrower bounds, and the parameters were resampled 1000 times within the new bounds for a new round of simulation. We repeated this iteration for ten times, and the last selected dataset was used to generate the 95% confidence intervals. All analyses and simulations were performed in MATLAB R 2019a.

Based on these estimated parameter values, we predicted the risk of secondary outbreak for different contact rate after lifting the quarantine (50%, 80%, 100%, 150% of contact rate in the public space before the lockdown), mask usage rate (95%, 80%, 50%, 10%), and the time to lift the quarantine (21th March, 28th March, 4st April, 11th April, 18th April and 25th April).

Table S1. The parameter table for the model simulation.

Parameter denotation	Parameter description	Range or 95%CI	Sources
$1/k_1$	The mean incubation time (days)	5.2 (4.1-7.0)	[9][9]
$1/k_2$	The mean time from mild to moderate symptoms (days)	5 (1-10)	[11]
$1/k_3$	The mean time from moderate to severe/critical symptoms (days)	5 (2-5)	[11]
$1/\rho_s$	The mean time from mild symptoms to spontaneous recovery (days)	10	[12]
τ	Detection rate in clinically diagnosed individuals with previous negative lab test results	0.0997 (0.0969-0.1034)	Model-estimated
μ_1	Death rate of undiagnosed individuals with severe/critical symptoms	0.0398 (0.0373-0.0428)	Model-estimated
μ_2	Death rate in clinically diagnosed individuals with severe/critical symptoms	0.0287 (0.0136-0.0441)×μ_1	Model-estimated
μ_3	Death rate of lab diagnosed individuals with severe/critical symptoms	0.4117 (0.3461-0.4808)×μ_1	Model-estimated
r	The mean number of members in a family	4	[13]
E(0)	The initial value of latent individuals	20.0446 (18.7456-21.3011)	Model-estimated
β	The per-act transmission probability while in contact with infected individuals with symptoms	0.09	[14]

ε_{hos}	The reduction in per-act transmission probability in a hospital setting	97%	Assumed
ε	The reduction in per-act transmission probability if infection is in latency	50% (10-90%)	[12]
$p_1(t)$	The usage rate of facial mask in the public space	$p_{ini} + \frac{\bar{p} - p_{ini}}{1 + \exp(-0.5(t - t_{ini}))}$	[15][16]
t_{ini}	Time when the behavioural changes began (2 day after quarantine)	15	[15]
p_{ini}	Background facial masks usage in the public space before the epidemic	10%	[17]
$\bar{p}$	Facial masks usage in the public space during quarantine	97.6% (97.3-99.3%)	[15][16]
p_2	The usage rate of facial mask in the private space	0%	[19]
p_3	The usage rate of facial mask in the hospital	100%	Field data
θ_1	The effectiveness of mask to prevent infection for the general population	0.8 (0.5-0.95)	[20][21]
θ_2	The effectiveness of mask to prevent infection for the medical staff	0.95 (0.9-1)	[20][21]
$m_1(t)$	The average number of daily contacts in the public space	$m_{ini} + \frac{0.2m_{ini} - m_{ini}}{1 + \exp(-0.3(t - t_{ini}))}$	[15]
m_{ini}	Background daily contact number in the public space	7.3492 (7.2157-7.5231)	Model-estimated
$m_2(t)$	The average number of daily contacts in the private space	$4 + \frac{12 - 4}{1 + \exp(-0.5(t - t_{ini}))}$	[13]
m_3	The average number of contacts between patients in a hospital setting	20 (10-30)	Field data
m_4	The average number of daily contacts between medical staff members and infected individuals in a hospital setting	60 (50-120)	Field data
$\delta_{t1}(t)$	Diagnosis rate of individuals with a mild symptom (lab diagnosis)	$0.05 + \frac{\overline{\delta_{t1}} - 0.05}{1 + \exp(-0.5(t - t_{ini}))}$	Assumed
$\overline{\delta_{t1}}$	Maximum diagnosis rate of individuals with mild symptom (lab diagnosis)	49.5% (48.6-53.7%)	Model-estimated

δ_{t2}	Diagnosis rate of individuals with a moderate symptom (lab diagnosis)	50%	[12]
δ_{t3}	Diagnosis rate of individuals with severe/critical symptoms (lab diagnosis)	100%	[11][12]
$\delta_{d1}(t)$	Diagnosis rate of individuals with a mild symptom (clinical diagnosis)	$0.5408\ (0.5366 - 0.5482) \times \delta_{t1}(t)$,	Model-estimated
δ_{d2}	Diagnosis rate of individuals with a moderate symptom (clinical diagnosis)	$0.5408\ (0.5366 - 0.5482) \times \delta_{t2}$	Model-estimated
δ_{d3}	Diagnosis rate of individuals with severe/critical symptoms (clinical diagnosis)	$0.5408\ (0.5366 - 0.5482) \times \delta_{t3}$	Model-estimated
$\rho_3(t)$	Recovery rate of treated individuals with severe/critical symptoms	$\dfrac{\overline{\rho_3}}{1 + \exp\left(-\rho_{3k}(t - t_\rho)\right)}$	Assumed
$\overline{\rho_3}$	Maximum recovery rate of treated individuals with severe/critical symptoms	0.2524 (0.2247-0.2884)	Model-estimated
ρ_{3k}	Growth rate of recovery rate	0.0276 (0.0121-0.0416)	Model-estimated
t_ρ	The time when the recovery rate is half of the maximal recovery rate	30.7530 (13.5650-45.6510)	Model-estimated
$\rho_1(t)$	Recovery rate of treated individuals with mild symptoms	$2.25 \times \rho_3(t)$	[22]
$\rho_2(t)$	Recovery rate of treated individuals with moderate symptoms	$1.38 \times \rho_3(t)$	[22]
$\rho_{d1}(t)$	Recovery rate of clinically diagnosed individuals with mild symptoms	$0.4087\ (0.2179 - 0.6911) \times \rho_1(t)$ during 12-18 Feb; 0, Otherwise	Model-estimated
$\rho_{d2}(t)$	Recovery rate of clinically diagnosed individuals with moderate symptoms	$0.4087\ (0.2179 - 0.6911) \times \rho_2(t)$ during 12-18 Feb; 0, Otherwise	Model-estimated
$\rho_{d3}(t)$	Recovery rate of clinically diagnosed individuals with severe/critical symptoms	$0.4087\ (0.2179 - 0.6911) \times \rho_3(t)$ during 12-18 Feb; 0, Otherwise	Model-estimated

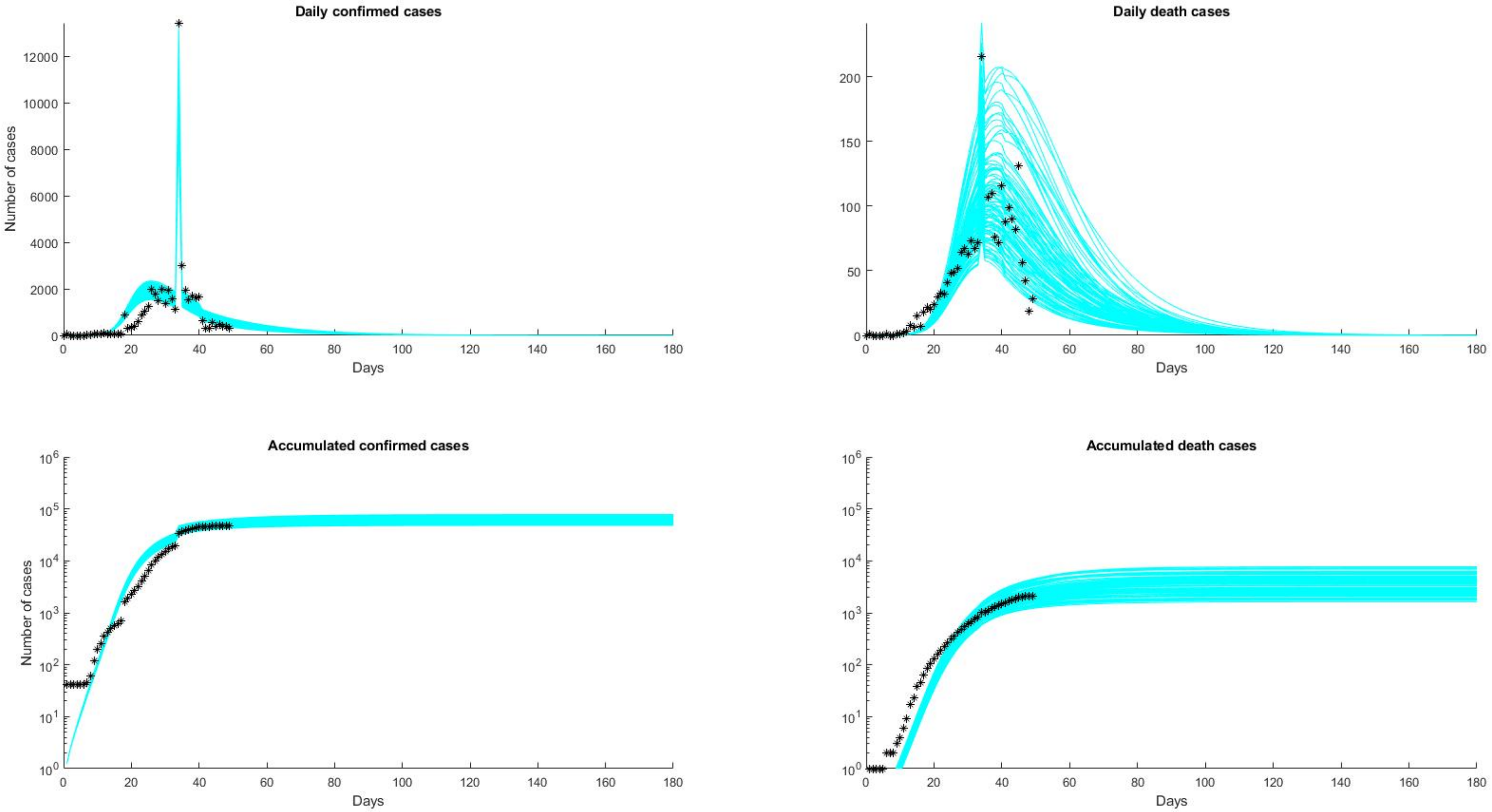

Figure S3. Model calibration to the number of daily and accumulated confirmed cases and deaths**.**

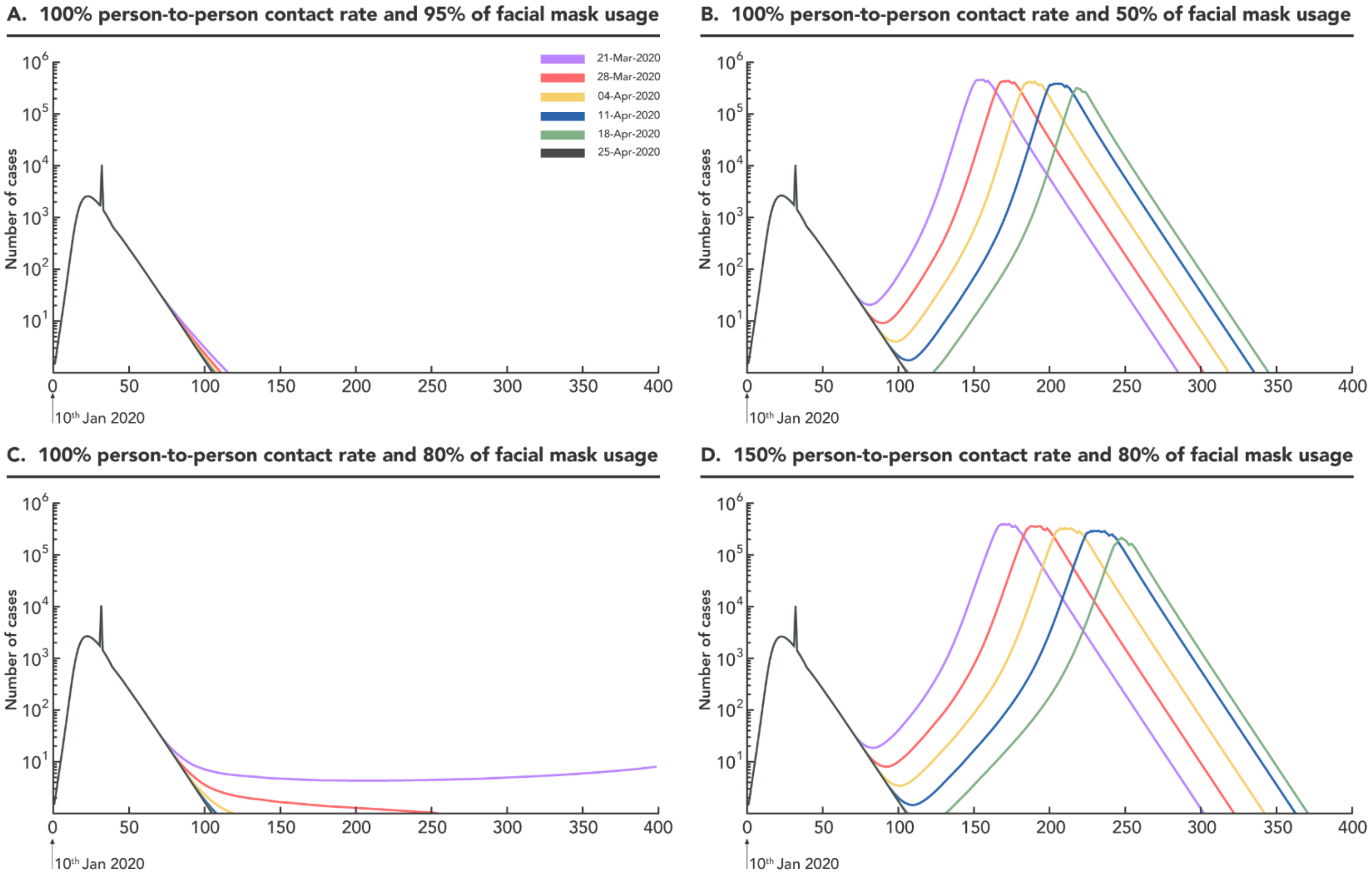

Figure S4a-b. Impact of different levels of facial mask usage (95% and 50%) on the COVID-19 epidemic in Wuhan city, on various quarantine lifting dates. The public contact rate is fixed at 100% (same as the pre-quarantine level).

Figure S4c-d. Impact of different levels of public contact rate (80% and 150%) on the COVID-19 epidemic in Wuhan city, on various quarantine lifting dates. The facial mask usage is reduced to 80%.

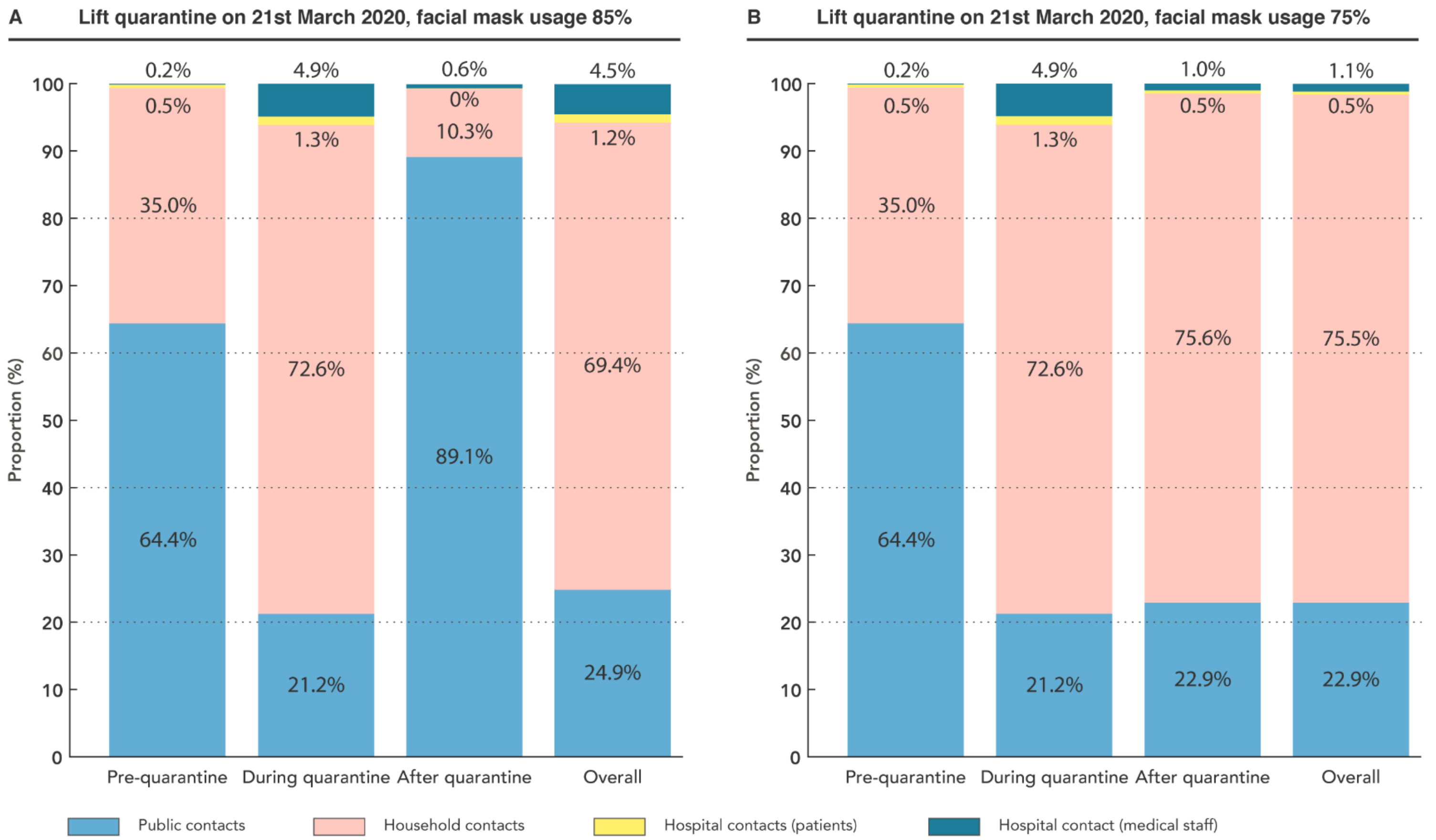

Figure S5. Comparison of the composition of transmission routes in two different resumption scenarios: (a) life city quarantine on 19th March 2020 with a 100% public contact rate and 85% facial mask usage; this leads to smooth decline of the epidemic; (b) life city quarantine on 19th March 2020 with a 100% public contact rate and 80% facial mask usage; this leads to a second major outbreak. (Blue: public contacts; Brown: household contacts; Yellow: hospital-acquired infections in non-COVID-19 patients; Purple: hospital-acquired infections in medical staff).

Table S2. Data source: reported cumulative confirmed cases, and deaths data in Wuhan city, Hubei Province, China [1,2].

Date	Cases	Deaths
2020-1-10	41	1
2020-1-11	41	1
2020-1-12	41	1
2020-1-13	41	1
2020-1-14	41	1
2020-1-15	41	2
2020-1-16	45	2
2020-1-17	62	2
2020-1-18	121	3
2020-1-19	198	4
2020-1-20	258	6
2020-1-21	363	9
2020-1-22	425	17
2020-1-23	495	23
2020-1-24	572	38
2020-1-25	618	45
2020-1-26	698	63
2020-1-27	1590	85
2020-1-28	1905	105
2020-1-29	2261	129
2020-1-30	2639	159
2020-1-31	3215	192
2020-2-1	4109	224
2020-2-2	5142	265
2020-2-3	6384	313
2020-2-4	8351	362
2020-2-5	10117	414
2020-2-6	11618	478
2020-2-7	13603	545
2020-2-8	14982	608
2020-2-9	16902	681
2020-2-10	18454	748
2020-2-11	19559	820
2020-2-12	32994	1036
2020-2-13	35991	1016
2020-2-14	37914	1123
2020-2-15	39462	1233
2020-2-16	41152	1309
2020-2-17	42752	1381
2020-2-18	44412	1497
2020-2-19	45027	1585
2020-2-20	45346	1684
2020-2-21	45660	1774
2020-2-22	46201	1856
2020-2-23	46607	1987
2020-2-24	47071	2043

2020-2-25	47441	2085
2020-2-26	47824	2104
2020-2-27	48137	2132
2020-2-28	48557	2169
2020-2-29	49122	2195
2020-3-1	49315	2227
2020-3-2	49426	2251
2020-3-3	49540	2282
2020-3-4	49671	2305
2020-3-5	49797	2328
2020-3-6	49871	2349
2020-3-7	49912	2370

References

[1]. Wuhan Municipal Health Commission. *Public announcement*. 2020; Available from: http://wjw.wuhan.gov.cn/front/web/list2nd/no/710.

[2]. Province, H.C.o.H. *Daily report of COVID-19*. 2020; Available from: http://wjw.hubei.gov.cn.

[3]. National Health Commission China. *National Health Commission of the People's Republic of China. New coronavirus pneumonia diagnosis and treatment plan (Version 5). 2020*. . 2020 [cited 2020 10th March]; Available from: http://www.nhc.gov.cn/yzygj/s7653p/202002/d4b895337e19445f8d728fcaf1e3e13a.shtml.

[4]. National Health Commission China. *National Health Commission of the People's Republic of China. New coronavirus pneumonia diagnosis and treatment plan (Version 6). 2020*. 2020 [cited 2020 10th March]; Available from: http://www.nhc.gov.cn/yzygj/s7653p/202002/8334a8326dd94d329df351d7da8aefc2.shtml.

[5]. Bai, Y., et al., *Presumed Asymptomatic Carrier Transmission of COVID-19*. JAMA, 2020.

[6]. Yu, P., et al., *A Familial Cluster of Infection Associated With the 2019 Novel Coronavirus Indicating Possible Person-to-Person Transmission During the Incubation Period*. The Journal of Infectious Diseases, 2020.

[7]. Offeddu, V., et al., *Effectiveness of Masks and Respirators Against Respiratory Infections in Healthcare Workers: A Systematic Review and Meta-Analysis*. Clin Infect Dis, 2017. **65**(11): p. 1934-1942.

[8]. Wuhan Municipal Health Commission. Daily report of COVID-19. http://wjw.wuhan.gov.cn/front/web/list2nd/no/710 [Accessed 4 Mar 2020]

[9]. Health Commission of Hubei Province. Daily report of COVID-19. http://wjw.hubei.gov.cn/ [Accessed 4 Mar 2020]

[10]. Li Q, Guan XH, Wu P, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. 2020. N Engl J Med. DOI:10.1056/NEJMoa2001316

[11]. Wang D, Hu B, Hu C. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA. 2020 Feb 7. doi: 10.1001/jama.2020.1585.

[12]. Wei Y, Lu Z, Du Z, et al. Fitting and forecasting the trend of COVID-19 by SEIR+CAQ dynamic model. Chin J Epidemiol. 2020; 41(4):470-475.

[13]. Chen B, Ai C, Ma L, et al. We should prepare for the transmission of COVID-19 in the long run: simulating the risk of the secondary outbreak after holiday. Journal of System Simulation. 2020; http://www.china-simulation.com/CN/Y2020/V0/I0/0

[14]. Liang J. National Health Commission: The growth rate has decreased to 25.69% in the 10th day for controlling the COVID-19. https://www.businesstimeschina.com/articles-420695-20200131-w1082e1082t8939.htm [Accessed 4 Mar 2020]

[15]. Kejixun. Liebao Mobile robot data: The facial mask useage rate reached 97.6% in Wuhan city during the epidemic. http://m.kejixun.com/article/200224/488396.shtml [Accessed 4 Mar 2020]

[16]. Huailiang Wu, Jian Huang, Casper J. P. Zhang, et al. Facemask shortage and the novel coronavirus (2019-nCoV) outbreak: Reflection on public health measures. https://doi.org/10.1101/2020.02.11.20020735 [Accessed 4 Mar 2020]

[17]. Mao M, Wang M, Zhang S. How many people wear facial masks in Beijing? A street mask observation practice was conducted here. https://www.thepaper.cn/newsDetail_forward_1592513 [Accessed 4 Mar 2020]

[18]. Gu J, Li J, Hao Y, et al. Bulletin of COVID-19 online survey. http://sph.sysu.edu.cn/article/1257 [Accessed 4 Mar 2020]

[19]. CCTV. How to protect yourself when returning? Whether it is necessary to wear facial masks at home? http://jiankang.cctv.com/2020/01/31/ARTIBRA7riu1PKMGS9BaqPkD200131.shtml [Accessed 4 Mar 2020]

[20]. Offeddu V, Yung CF, Fong Low MS, et al. Effectiveness of masks and respirators against respiratory infections in healthcare workers: A systematic review and meta-analysis. Clin Infect Dis. 2017;65(11):1934-1942.

[21]. Xinghuan Wang, Zhenyu Pan, Zhenshun Cheng, Association between COVID-19transmission and N95 respirator use. doi: https://doi.org/10.1101/2020.02.18.20021881

[22]. World Health Organization. Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19). https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf [Accessed 4 Mar 2020]

[23]. National Health Commission of the People's Republic of China. The 5th version diagnosis and treatment guidelines of COVID-19. http://www.nhc.gov.cn/yzygj/s7653p/202002/d4b895337e19445f8d728fcaf1e3e13a.shtml [Accessed 4 Mar 2020]