Basic reproduction number of 2019 Novel Coronavirus Disease in Major Endemic Areas of China: A latent profile analysis

Honglv Xu a,b,c,d, Min Yuan e, Liya Ma a,b,c,d, Meng Liu a,b,c,d, Yi Zhang a,b,c,d, Wenwen Liu a,b,c,d, Hong Gan a,b,c,d, Fangbiao Tao a,b,c,d

a Department of Maternal, Child and Adolescent Health, School of Public Health, Anhui Medical University, 81 Meishan Road, Hefei, Anhui, 230032, PR China

b Key Laboratory of Population Health Across Life Cycle (Anhui Medical University) , Ministry of Education of the People’s Republic of China, No 81 Meishan Road, Hefei, 230032, Anhui, PR China

c NHC Key Laboratory of Study on Abnormal Gametes and Reproductive Tract, No 81 Meishan Road, Hefei 230032, Anhui, PR China

d Anhui Provincial Key Laboratory of Population Health and Aristogenics, No 81 Meishan Road, Hefei, 230032, Anhui, PR China

e Center for Big Data Science in Health, School of Health Service Management, Anhui Medical University, Hefei 230032, China

*Corresponding author: Professor Fangbiao TAO, Department of Maternal, Child and Adolescent Health, School of Public Health, Anhui Medical University, Meishan Road 81, Hefei, Anhui, PR China, 230032

NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
E-mail: taofangbiao@126.com

Tel: +86-511-56161155

Fax: +86-511-56161155

Abstract

Objective The aim of the study is to analyze the latent class of basic reproduction number (R<sub>0</sub>) trend of 2019 novel coronavirus disease (COVID-19) in major endemic areas of China. Methods The provinces that reported more than 500 cases of COVID-19 till February 18, 2020 were selected as the major endemic area. The Verhulst model was used to fit the growth rate of cumulative confirmed cases. The R<sub>0</sub> of COVID-19 was calculated using the parameters of severe acute respiratory syndrome (SARS) and COVID-19, respectively. The latent class of R<sub>0</sub> was analyzed using a latent profile analysis model. Results The median R<sub>0</sub> calculated from SARS and COVID-19 parameters were 1.84 - 3.18 and 1.74 - 2.91, respectively. The R<sub>0</sub> calculated from the SARS parameters was greater than that of calculated from the COVID-19 parameters (Z = -4.782 - -4.623, P < 0.01). Both R<sub>0</sub> can be divided into three latent classes. The initial value of R<sub>0</sub> in class 1 (Shandong Province, Sichuan Province and Chongqing Municipality) was relatively low and decreases slowly. The initial value of R<sub>0</sub> in class 2 (Anhui Province, Hunan Province, Jiangxi Province, Henan Province, Zhejiang Province, Guangdong Province and Jiangsu Province) was relatively high and decreases rapidly. Moreover, the initial value of R<sub>0</sub> of class 3 (Hubei Province) was between that of class 1 and class 2, but the higher level of R<sub>0</sub> lasts longer and decreases slowly. Conclusion The results indicated that overall trend of R<sub>0</sub> has been falling with the strengthening of China's comprehensive prevention and control measures for COVID-19, however,
presents regional differences.

**Keywords:** 2019 novel coronavirus disease; Basic reproduction number; Latent categories; Trends; Epidemiology

1. Introduction

Of particular concern is that 2019 novel coronavirus disease (COVID-19) outbroke in Wuhan, Hubei Province at the end of 2019, and quickly spread to the whole country of China (Liu et al., 2020; Lu et al., 2020). COVID-19, an infectious disease caused by 2019-nCoV, can be transmitted through droplets, aerosols, and contact (Chen et al., 2020; Li et al., 2020). The main clinical features of the case are fever, dry cough, and fatigue. There are also mild cases and asymptomatic pathogen carriers (Guo et al., 2020; Huang et al., 2020). Evidence demonstrates that COVID-19 is extremely infectious, even during the incubation period, and the entire population is susceptible (Nishiura et al., 2020; Thompson, 2020). It has a higher case fatality rate, posed great threats to public health and attracted an enormous concern (Yang et al., 2020). Currently, COVID-19 has become widespread around the world (Sommer et al., 2020; Sorbello et al., 2020). For a new infectious disease, it is important to identify the epidemic characteristics and transmission dynamics for the prevention and control of the infectious disease (Kannan et al., 2020).

It is generally known that basic reproduction number ($R_0$) is an important parameter for studying the dynamics of infectious disease transmission for describing the ability to spread of an
infectious source (Ganyani et al., 2018; Sato, 2019). $R_0$ is defined as the average number of secondary cases that an infected subject produces over its infectious period in a susceptible and uninfected population (Chang, 2017). There has been increasing concern that $R_0$ of COVID-19 is used to assess the spread of infectious diseases, predict epidemic trends, and evaluate the effectiveness of prevention and control measures (Chowell et al., 2007; Park et al., 2020). Although some previous studies have investigated the $R_0$ of COVID-19, these studies are prediction estimates based on data from the early stages of the COVID-19 epidemic. Research data is very limited and results are inconsistent (Wu et al., 2020; Zhao et al., 2020; Zhao and Chen, 2020; Zhou et al., 2020). The present study analyzed the latent class of $R_0$ of COVID-19 in major endemic areas that reported more than 500 cases of COVID-19 in China. We evaluate the effect of China's prevention and control measures based on the trend of $R_0$, and provide a basis for further prevention and control of COVID-19 and other emerging infectious diseases.

2. Materials and methods

2.1 Materials

The major endemic areas of COVID-19 is defined as the area where the cumulative number of cases more than 500 of COVID-19 has been diagnosed by 24:00 on February 18, 2020. These areas include Guangdong Province, Jiangxi Province, Hunan Province, Chongqing Municipality, Sichuan Province, Hubei Province, Anhui Province, Zhejiang Province, Jiangsu Province, Henan Province and Shandong Province. We collected the cumulative number of cases of COVID-19 from the official websites of the health commission in
these areas. In addition, we collected the main prevention and control measures for COVID-19 from the websites of provincial governments.

2.2 Methods

The Verhulst model was used to fit the growth rate of cumulative number of cases (Tang et al., 2020; Zeng et al., 2003). Verhulst curvilinear equation was as follows:

\[
y = \frac{a}{1 + \frac{c}{b} \exp(-cx)}
\]

(1)

\[
r = \frac{dy}{ydx}
\]

(2)

where \(a\), \(b\), and \(c\) are parameter constants, and \(r\) is the growth rate. We calculated the \(R_0\) of COVID-19 using the following equation (Wallinga and Lipsitch, 2007):

\[
R_0 = (1 + r \times IP) \times (1 + r \times SI)
\]

(3)

where \(r\) is the growth rate, \(IP\) is incubation period (IP), \(SI\) is the serial interval (SI) from the onset of case \(i\) to infection of case \(ii\). We calculated \(R_0\) based on the IP and SI of COVID-19 (reported by the Chinese Center for Disease Control and Prevention) and severe acute respiratory syndrome (SARS). The IP and SI of COVID-19 are 5.2 and 7.5, respectively (Li et al., 2008). The IP and SI of SARS are 6.0 and 8.4, respectively (Lipsitch et al., 2003). We described the changing trend of \(R_0\) with time in each province, and analyzed the latent class according to the trend of \(R_0\). Moreover, the major prevention and control measures for COVID-19 in each major endemic area are sorted out. We used the WPS 2019 to draw a Nightingale rose diagram based on the frequency of prevention and control measures were adopted.

2.3 Statistical analyses
All statistical analyses were performed using R (R-3.5.1, R Core Team) and Mplus (Mplus version 7.4). Methods for analyzing include descriptive statistical analysis and model estimation. The Verhulst model was used to fit the growth rate of the cumulative number of cases and calculate R₀ in R software. Use the range between the minimum and maximum values, the 25th percentile (P₂₅), the 50th percentile (P₅₀), and the 75th percentile (P₇₅) to describe the distribution of R₀. The Wilcoxon signed-rank test was used to compare the differences of R₀ calculated from the COVID-19 parameter and the SARS parameter. A latent profile analysis (LPA) was used to analyze the latent class of R₀ trend in Mplus software.

3 Results

3.1 The trend of the cumulative number of cases

Figure 1 shows the trend of the cumulative number of COVID-19. It shows S-shaped growth. Hubei Province has the largest cumulative number of cases and the fastest growth. Except Hubei Province, the trends of the cumulative number of cases in several other provinces were observed in the phenomenon of classification. The number of cases in class 1 (Henan Province, Zhejiang Province, and Guangdong Province) was relatively large and has increased rapidly. The number of cases in class 2 (Anhui Province, Hunan Province and Jiangxi Province) and the growth rate were at a medium level. The number of cases in class 3 (Shandong Province, Jiangsu Province, Sichuan Province, and Chongqing Municipality) and the growth rate were relatively low. In general, except Hubei Province, the major epidemic areas of COVID-19 in China reached the highest peaks of the "S" curve around February 15.
3.2 The growth rate trend of the cumulative number of cases

The growth rate of cumulative number of COVID-19 in Hubei Province is 0.03 - 0.20. Especially, the growth rate of 0.24 continued until January 26, 2020, and the growth rate of 0.23 - 0.22 continued until January 31, 2020. Then, the growth rate shows a clear downward trend in Hubei Province. Except Chongqing Municipality, Sichuan Province, and Shandong Province (the growth rates were 0.14 - 0.20), the initial growth rates (0.25 - 0.32) of all other provinces were higher than those of Hubei Province, but it started to decline rapidly after 2 - 3 days. (Figure 2)

3.3 The $R_0$ trend of COVID-19

Table 1 shows the distribution of $R_0$. The median $R_0$ calculated from SARS parameters is 1.84 - 3.18, and the $R_0$ calculated from COVID-19 parameters is 1.74 - 2.91. Overall, the former is greater than the latter ($Z_1 = -4.782 - -4.623, P < 0.01$). Figure 2 shows the $R_0$ trend of COVID-19. The trends of $R_0$ calculated from the two parameters are basically consistent. It was showed a gradual downward trend of $R_0$ in each province from January 20 to February 18, 2020. The $R_0$ in Hubei Province declined slowly before January 31, and then showed a significant downward trend. Except Chongqing Municipality, Sichuan Province, and Shandong Province, the initial $R_0$ in all other provinces was higher than that of Hubei Province, but the decline rate of $R_0$ is higher than Hubei Province. As of February 18, 2020, except Hubei Province ($R_0 = 1.20$) and Shandong Province ($R_0 = 1.21$), the $R_0$ (1.01 - 1.06) were close to 1 in all other provinces.

3.4 The latent class of $R_0$

We constructed five latent class models in the latent profile analysis. The three-class model was finally selected according to the model fitting index, latent class probability, and the
interpretability of the model. Table 2 shows the fitting index and latent class probability of
the model. There are three latent classes of the $R_0$ calculated from SARS parameters and
COVID-19 parameters. Class 1 includes Shandong Province, Sichuan Province and
Chongqing Municipality. Class 2 includes Anhui Province, Hunan Province, Jiangxi
Province, Henan Province, Zhejiang Province, Guangdong Province and Jiangsu Province.
Class 3 includes Hubei Province. Figure 3 shows the $R_0$ trend in different latent classes. The
initial value of class 1 $R_0$ was relatively low and decreases slowly. The initial value of class
2 $R_0$ was relatively high and decreased rapidly. The initial value of class 3 $R_0$ was between
class 1 and class 2, but high levels of $R_0$ lasted longer and declined slowly.

3.5 The main prevention and control measures for COVID-19

Figure 4 shows the main prevention and control measures were adopted for COVID-19 in major
endemic areas of China. These measures include activating first-level public health
emergency response, wearing masks, conducting epidemiological investigations, screening
of key populations, temporary traffic control, closing public places (e.g. cinemas, internet
cafes, etc.), monitoring body temperature, symptom screening, medical observation, the
"four early" measures (early detection, early reporting, early isolation and early treatment),
the "four concentrated" treatment measures (concentrated cases, concentrated experts,
concentrated resources, concentrated treatment), quarantine oneself, lockdown a city,
disinfection in public areas, and so on.

4. Discussion
The present study suggests that the $R_0$ of COVID-19 calculated from SARS parameter is greater than the $R_0$ calculated from COVID-19 parameters (the median of $R_0$ is 1.84 - 3.18 and 1.74 - 2.91, respectively). Our findings may indicate that the epidemiological characteristics of COVID-19 and SARS are different. Coronavirus has caused three large-scale epidemics in humans in the past 20 years, including SARS in 2002, Middle East respiratory syndrome (MERS) in 2012 and COVID-19 in 2019 (Dye and Gay, 2003; Zaki et al., 2012). From the number of infections, deaths, and epidemic areas, COVID-19 threatens human health more than SARS and MERS (Memish et al., 2020; Sayed et al., 2020; Wilder-Smith et al., 2020). The $R_0$ of COVID-19 in our study is lower than that of SARS (3.1 - 4.2) and MERS (2.0 - 6.7) (Wallinga and Teunis, 2004; Majumder et al., 2014; Chang, 2017). These findings are consistent with previous studies on the infectious capacity of COVID-19 is lower than that of SARS and MERS (Zhou, et al., 2020). Additionally, the $R_0$ calculated from the COVID-19 parameters in this work is similar to the $R_0$ (2.38 - 2.72, 2.47 - 2.86) estimated in China Other studies in China (Geng et al., 2020; Wu, et al., 2020). Also, it is also similar to $R_0$ (2.4 - 2.8) of COVID-19 in Japan (Kuniya, 2020). Nevertheless, our calculated $R_0$ is lower than that estimated using the epidemic data in the early epidemic of the COVID-19 in Wuhan ($R_0 = 1.4 - 3.9$), Hubei Province ($R_0 = 2.80 - 4.48$), and China (2.8 - 3.3) (Li, et al., 2008; Wang, et al., 2020; Zhou, et al., 2020).

On the whole, $R_0$ of COVID-19 in each province is gradually decreasing. It is believed that the powerful combined prevention and control measures adopted for COVID-19 by the Chinese government have had obvious effects. These combined measures and the successful experience prevention and control for COVID-19 of China can provide a reference for other countries. There
is mounting evidence that implementing the combined measures could significantly reduce the
number of cases such as workplace distancing and school closure, quarantining infected
individuals and their family members, social distancing and quarantine measures (Anderson et al.,
2020; Koo et al., 2020). A study in Singapore showed that the combined intervention will reduce
the estimated number of infections by 99.3%, 93.0%, and 78.2% when $R_0$ was 1.5, 2.0, and 2.5,
respectively, compared with the baseline scenario (Koo, et al., 2020). Some researchers believe
that isolation of cases, contact tracing, social distancing are used to control outbreaks of infectious
diseases (Anderson, et al., 2020). Specifically, contact tracing is a key activity in reducing the
spread of the epidemic. A new study from the UK suggests that to control the majority of
COVID-19 outbreaks, for an $R_0$ of 3.5 more than 90% of contacts had to be traced, and for $R_0$ of
2.5 more than 70% of contacts had to be traced (Hellewell et al., 2020).

The results of the latent profile analysis showed that there are three latent class of $R_0$,
and the trends of $R_0$ in each latent class have their own unique characteristics. Observed
findings indicate that although the Chinese government has adopted the overall prevention
and control measures of "a board of chess in China, suit one's measures to local conditions", the
effects are not entirely consistent. More specifically, the initial value of $R_0$ in class 1 was
relatively low, and the decline was slow. The possible explanations are that these areas have taken
active measures after the COVID-19 epidemic in Wuhan, and the spread of COVID-19 was well
controlled from the beginning. The initial value of $R_0$ in class 2 was relatively high, even higher
than that of Hubei Province. However, the $R_0$ declined rapidly, and the decline rate was the fastest
of the three latent classes. The possible reason is that the measures adopted at the beginning of the
epidemic of COVID-19 were not effective. Then, the epidemic was effectively controlled after
quickly adjusting the measures in these areas, and the infectious capacity of COVID-19 decreased rapidly. The initial value of $R_0$ in class 3 (Hubei Province) was between that of type 1 and type 2, but the higher level of $R_0$ lasts longer and decreases slowly. Wuhan City, Hubei Province, is the first area in China where COVID-19 was found to be endemic. Due to the lack of understanding of the emerging infectious disease pathogens, transmission routes, susceptible populations, disease characteristics, epidemic characteristics, and other unknown reasons, the $R_0$ of COVID-19 lasted longer at higher levels in Hubei Province. In other words, before January 31, Hubei Province COVID-19 was strongly infectivity. Therefore, our findings agree that the adoption of active prevention and control measures at the beginning of the epidemic can effectively control the spread of COVID-19.

What's more, the $R_0$ of COVID-19 in Hubei Province and Shandong Province were around 1.2 by February 18, and there is still a certain risk of transmission. The $R_0$ (1.01 - 1.06) in other provinces were close to 1, and still greater than 1. It is widely recognized that $R_0$ can reflect the epidemic trend of infectious diseases. When $R_0 > 1$, the greater the $R_0$, the greater the infectious ability of infectious diseases and the greater the number of cases. When $R_0 < 1$, means the epidemic of infectious diseases will gradually end. The optimal targeting of taking effective interventions is to control the $R_0$ less than 1 (Delamater et al., 2019). At present, China has gradually resumed work and school, and population movement and crowd accumulation have further increased the risk of COVID-19 transmission and the difficulty of prevention and control. Furthermore, COVID-19 has been endemic and spread in many countries around the world, and international import cases may cause a secondary epidemic.
(Lai et al., 2020; Palacios et al., 2020). Consequently, China also needs to continue to strengthen its prevention and control for COVID-19.

The present study had several strengths and limitations. The main strength of this work was to calculate the $R_0$ based on the epidemic data of major epidemic areas in China as of February 18. However, previous research on $R_0$ was almost prediction and estimation based on the limited epidemiological data of COVID-19 in Wuhan in the early days. Another strength was to analyze the latent class of $R_0$ and explore the regional differences in prevention and control effects. The findings presented in this study have implications for the preliminary evaluation of the effectiveness of prevention and control measures for COVID-19 adopted in China. In addition, the research results can provide experience for other countries to respond to COVID-19, and also provide support for previous prediction studies. There are several limitations to our study. Above all, the calculation of $R_0$ is affected by multiple parameters and various factors (Delamater, et al., 2019). And yet the factors considered are relatively single in this study. Additional research is necessary to confirm the accuracy of the $R_0$, considering the large uncertainties around estimates of $R_0$ and the duration of infectiousness (Rebuli et al., 2018; Prem et al., 2020).

Additionally, there are many methods for calculating $R_0$ in the world (Chowell, et al., 2007), but this study did not use multiple methods to compare the results. Finally, although this study sorts out the prevention and control measures for COVID-19 in major endemic areas in China, it is difficult to quantitatively evaluate the effects of various measures.

5. Conclusion
Overall, we found that the $R_0$ of COVID-19 shows a downward trend in major endemic areas in China, and there are regional differences (three latent classes). Actively adopting combined prevention and control measures in the early stages of the epidemic can effectively control COVID-19.

**Author contributions**

Fangbiao TAO designed the study. HongLv XU took primary responsibility for writing the manuscript, managed the literature searches and analyses, and undertook the statistical analysis. Min Yuan, Liya Ma, MengLiu, Yi Zhang, Wenwen Liu and Hong Gan undertook the acquisition of the data. All authors contributed to and approved the final manuscript.

**Acknowledgements**

This work was supported by the Anhui Medical University Emergency Key Research Project for Novel Coronavirus Pneumonia (YJGG202001) and Emergency Research Project, Anhui Provincial Department of Science and Technology, Anhui Provincial Health Commission (202004a07020002).

**Competing interest**

All authors declare no conflict of interest.

6. **References**

Anderson, R.M., Heesterbeek, H., Klinkenberg, D., Hollingsworth, T.D., 2020. How will country-based mitigation measures influence the course of the COVID-19 epidemic? Lancet 395 (10228), 931-934. Doi: 10.1016/S0140-6736(20)30567-5
Chang, H.J., 2017. Estimation of basic reproduction number of the Middle East respiratory syndrome coronavirus (MERS-CoV) during the outbreak in South Korea, 2015. Biomed. Eng. Online 16 (1), 79. Doi: 10.1186/s12938-017-0370-7

Chen, N., Zhou, M., Dong, X., Qu, J., Gong, F., Han, Y., Qiu, Y., Wang, J., Liu, Y., Wei, Y., Xia, J., Yu, T., Zhang, X., Zhang, L., 2020. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet 395 (10223), 507-513. Doi: 10.1016/S0140-6736(20)30211-7

Chowell, G., Nishiura, H., Bettencourt, L.M., 2007. Comparative estimation of the reproduction number for pandemic influenza from daily case notification data. J. R. Soc. Interface 4 (12), 155-166. Doi: 10.1098/rsif.2006.0161

Delamater, P.L., Street, E.J., Leslie, T.F., Yang, Y.T., Jacobsen, K.H., 2019. Complexity of the Basic Reproduction Number (R0). Emerg. Infect. Dis. 25 (1), 1-4. Doi: 10.3201/eid2501.171901

Dye, C., Gay, N., 2003. Epidemiology. Modeling the SARS epidemic. Science 300 (5627), 1884-1885. Doi: 10.1126/science.1086925

Ganyani, T., Faes, C., Chowell, G., Hens, N., 2018. Assessing inference of the basic reproduction number in an SIR model incorporating a growth-scaling parameter. Stat. Med. 37 (29), 4490-4506. Doi: 10.1002/sim.7935

Geng, H., Xu A., Wang, X., Zhang, Y., Yin, X., Ma, M., Lv, J., 2020. Analysis of the role of current prevention and control measures in the epidemic of new coronavirus based on SEIR model. Journal of Jinan University(Natural Science & Medicine Edition), 41(1):1-7.
Guo, Y.R., Cao, Q.D., Hong, Z.S., Tan, Y.Y., Chen, S.D., Jin, H.J., Tan, K.S., Wang, D.Y., Yan, Y., 2020. The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak - an update on the status. Mil Med Res 7 (1), 11. Doi: 10.1186/s40779-020-00240-0

Hellewell, J., Abbott, S., Gimma, A., Bosse, N.I., Jarvis, C.I., Russell, T.W., Munday, J.D., Kucharski, A.J., Edmunds, W.J., Funk, S., Eggo, R.M., 2020. Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. Lancet Glob Health 8 (4), e488-e496. Doi: 10.1016/S2214-109X(20)30074-7

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., Zhang, L., Fan, G., Xu, J., Gu, X., Cheng, Z., Yu, T., Xia, J., Wei, Y., Wu, W., Xie, X., Yin, W., Li, H., Liu, M., Xiao, Y., Gao, H., Guo, L., Xie, J., Wang, G., Jiang, R., Gao, Z., Jin, Q., Wang, J., Cao, B., 2020. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 395 (10223), 497-506. Doi: 10.1016/S0140-6736(20)30183-5

Kannan, S., Shaik, S.A.P., Sheeza, A., Hemalatha, K., 2020. COVID-19 (Novel Coronavirus 2019) - recent trends. Eur Rev Med Pharmacol Sci 24 (4), 2006-2011. Doi: 10.26355/eurrev_202002_20378

Koo, J.R., Cook, A.R., Park, M., Sun, Y., Sun, H., Lim, J.T., Tam, C., Dickens, B.L., 2020. Interventions to mitigate early spread of SARS-CoV-2 in Singapore: a modelling study. Lancet Infect. Dis. Doi: 10.1016/S1473-3099(20)30162-6

Kuniya, T., 2020. Prediction of the Epidemic Peak of Coronavirus Disease in Japan, 2020. J Clin
Lai, C.C., Shih, T.P., Ko, W.C., Tang, H.J., Hsueh, P.R., 2020. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. Int J Antimicrob Agents 55 (3), 105924. Doi: 10.1016/j.ijantimicag.2020.105924

Li, J.Y., You, Z., Wang, Q., Zhou, Z.J., Qiu, Y., Luo, R., Ge, X.Y., 2020. The epidemic of 2019-novel-coronavirus (2019-nCoV) pneumonia and insights for emerging infectious diseases in the future. Microbes Infect. 22 (2), 80-85. Doi: 10.1016/j.micinf.2020.02.002

Lipsitch, M., Cohen, T., Cooper, B., Robins, J.M., Ma, S., James, L., Gopalakrishna, G., Chew, S.K., Tan, C.C., Samore, M.H., Fisman, D., Murray, M., 2003. Transmission dynamics and control of severe acute respiratory syndrome. Science 300 (5627), 1966-1970. Doi: 10.1126/science.1086616

Li, Q., Guan, X., Wu, P., et al., 2020. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. New Engl J Med, 382(13):1199-1207. Doi: 10.1056/NEJMoa2001316

Liu, K., Fang, Y.Y., Deng, Y., Liu, W., Wang, M.F., Ma, J.P., Xiao, W., Wang, Y.N., Zhong, M.H., Li, C.H., Li, G.C., Liu, H.G., 2020. Clinical characteristics of novel coronavirus cases in tertiary hospitals in Hubei Province. Chin Med J (Engl). Doi: 10.1097/CM9.0000000000000744

Lu, R., Zhao, X., Li, J., Niu, P., Yang, B., Wu, H., Wang, W., Song, H., Huang, B., Zhu, N., Bi, Y., Ma, X., Zhan, F., Wang, L., Hu, T., Zhou, H., Hu, Z., Zhou, W., Zhao, L., Chen, J., Meng, Y.,
Wang, J., Lin, Y., Yuan, J., Xie, Z., Ma, J., Liu, W.J., Wang, D., Xu, W., Holmes, E.C., Gao, G.F., Wu, G., Chen, W., Shi, W., Tan, W., 2020. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. Lancet 395 (10224), 565-574. Doi: 10.1016/S0140-6736(20)30251-8

Majumder, M.S., Rivers, C., Lofgren, E., Fisman, D., 2014. Estimation of MERS-Coronavirus Reproductive Number and Case Fatality Rate for the Spring 2014 Saudi Arabia Outbreak: Insights from Publicly Available Data. PLoS Curr 6. Doi: 10.1371/currents.outbreaks.98d2f8f3382d84f390736cd5f5fe133c

Memish, Z.A., Perlman, S., Van Kerkhove, M.D., Zumla, A., 2020. Middle East respiratory syndrome. Lancet. Doi: 10.1016/S0140-6736(19)33221-0

Nishiura, H., Linton, N.M., Akhmetzhanov, A.R., 2020. Serial interval of novel coronavirus (COVID-19) infections. Int. J. Infect. Dis. Doi: 10.1016/j.ijid.2020.02.060

Palacios, C.M., Santos, E., Velazquez, C.M., Leon, J.M., 2020. COVID-19, a worldwide public health emergency. Rev. Clin. Esp. Doi: 10.1016/j.rce.2020.03.001

Park, S.W., Bolker, B.M., 2020. A Note on Observation Processes in Epidemic Models. Bull Math Biol 82 (3), 37. Doi: 10.1007/s11538-020-00713-2

Prem, K., Liu, Y., Russell, T.W., Kucharski, A.J., Eggo, R.M., Davies, N., Jit, M., Klepac, P., 2020. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. Lancet Public Health. Doi: 10.1016/S2468-2667(20)30073-6
Rebuli, N.P., Bean, N.G., Ross, J.V., 2018. Estimating the basic reproductive number during the early stages of an emerging epidemic. Theor. Popul. Biol. 119, 26-36. Doi: 10.1016/j.tpb.2017.10.004

Sato, K., 2019. Basic reproduction number of SEIRS model on regular lattice. Math. Biosci. Eng. 16 (6), 6708-6727. Doi: 10.3934/mbe.2019335

Sayed, A.S., Malek, S.S., Abushahba, M.F., 2020. Seroprevalence of Middle East Respiratory Syndrome Corona Virus in dromedaries and their traders in upper Egypt. J Infect Dev Ctries 14 (2), 191-198. Doi: 10.3855/jidc.10862

Sommer, P., Lukovic, E., Fagley, E., Long, D., Sobol, J., Heller, K., Moitra, V., Pauldine, R., O’Connor, M., Shahul, S., Nunnally, M., Tung, A., 2020. Initial Clinical Impressions of the Critical Care of COVID-19 Patients in Seattle, New York City, and Chicago. Anesth. Analg. Doi: 10.1213/ANE.0000000000004830

Sorbello, M., El-Boghdalhy, K., Di Giacinto, I., Cataldo, R., Esposito, C., Falcetta, S., Merli, G., Cortese, G., Corso, R.M., Bressan, F., Pintaudi, S., Greif, R., Donati, A., Petrini, F., 2020. The Italian COVID-19 outbreak: experiences and recommendations from clinical practice. Anaesthesia. Doi: 10.1111/anae.15049

Tang, L., Lu, Y., 2020. Study of the grey Verhulst model based on the weighted least square method. Physica A: Statistical Mechanics and its Applications. Doi.org/10.1016/j.physa.2019.123615

Thompson, R.N., 2020. Novel Coronavirus Outbreak in Wuhan, China, 2020: Intense Surveillance Is Vital for Preventing Sustained Transmission in New Locations. J Clin Med 9 (2). Doi: 10.3390/jcm9020321

Rebuli, N.P., Bean, N.G., Ross, J.V., 2018. Estimating the basic reproductive number during the early stages of an emerging epidemic. Theor. Popul. Biol. 119, 26-36. Doi: 10.1016/j.tpb.2017.10.004

Sato, K., 2019. Basic reproduction number of SEIRS model on regular lattice. Math. Biosci. Eng. 16 (6), 6708-6727. Doi: 10.3934/mbe.2019335

Sayed, A.S., Malek, S.S., Abushahba, M.F., 2020. Seroprevalence of Middle East Respiratory Syndrome Corona Virus in dromedaries and their traders in upper Egypt. J Infect Dev Ctries 14 (2), 191-198. Doi: 10.3855/jidc.10862

Sommer, P., Lukovic, E., Fagley, E., Long, D., Sobol, J., Heller, K., Moitra, V., Pauldine, R., O’Connor, M., Shahul, S., Nunnally, M., Tung, A., 2020. Initial Clinical Impressions of the Critical Care of COVID-19 Patients in Seattle, New York City, and Chicago. Anesth. Analg. Doi: 10.1213/ANE.0000000000004830

Sorbello, M., El-Boghdalhy, K., Di Giacinto, I., Cataldo, R., Esposito, C., Falcetta, S., Merli, G., Cortese, G., Corso, R.M., Bressan, F., Pintaudi, S., Greif, R., Donati, A., Petrini, F., 2020. The Italian COVID-19 outbreak: experiences and recommendations from clinical practice. Anaesthesia. Doi: 10.1111/anae.15049

Tang, L., Lu, Y., 2020. Study of the grey Verhulst model based on the weighted least square method. Physica A: Statistical Mechanics and its Applications. Doi.org/10.1016/j.physa.2019.123615

Thompson, R.N., 2020. Novel Coronavirus Outbreak in Wuhan, China, 2020: Intense Surveillance Is Vital for Preventing Sustained Transmission in New Locations. J Clin Med 9 (2). Doi:
Wallinga, J., Lipsitch, M., 2007. How generation intervals shape the relationship between growth rates and reproductive numbers. Proc Biol Sci 274 (1609), 599-604. Doi: 10.1098/rspb.2006.3754

Wallinga, J., Teunis, P., 2004. Different epidemic curves for severe acute respiratory syndrome reveal similar impacts of control measures. Am. J. Epidemiol. 160 (6), 509-516. Doi: 10.1093/aje/kwh255

Wang, Y., You, X.Y., Wang, Y.J., Peng, L.P., Du ZC, Gilmour, S., Yoneoka, D., Gu, J., Hao, C., Hao, Y.T., Li, J.H., 2020. Estimating the basic reproduction number of COVID-19 in Wuhan, China. Chinese Journal of Epidemiology. 41 (4), 476-479. Doi: 10.3760/cma.j.cn112338-20200210-00086

Wilder-Smith, A., Chiew, C.J., Lee, V.J., 2020. Can we contain the COVID-19 outbreak with the same measures as for SARS? Lancet Infect. Dis. Doi: 10.1016/S1473-3099(20)30129-8

Wu, J.T., Leung, K., Leung, G.M., 2020. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 395 (10225), 689-697. Doi: 10.1016/S0140-6736(20)30260-9

Yang, S., Cao, P., Du P, Wu, Z., Zhuang, Z., Yang, L., Yu, X., Zhou, Q., Feng, X., Wang, X., Li, W., Liu, E., Chen, J., Chen, Y., He, D., 2020. Early estimation of the case fatality rate of COVID-19 in mainland China: a data-driven analysis. Ann Transl Med 8 (4), 128. Doi: 10.21037/atm.2020.02.66
Zaki, A.M., van Boheemen, S., Bestebroer, T.M., Osterhaus, A.D., Fouchier, R.A., 2012. Isolation of a novel coronavirus from a man with pneumonia in Saudi Arabia. N Engl J Med 367 (19), 1814-1820. Doi: 10.1056/NEJMoa1211721

Zeng, B., Tong, M., Ma, X., 2020. A new-structure grey Verhulst model: Development and performance comparison. Appl math model, 81(5): 522-537. Doi:10.1016/j.apm.2020.01.014

Zhao, S., Chen, H., 2020. Modeling the epidemic dynamics and control of COVID-19 outbreak in China. Quant Biol, 1-9. Doi: 10.1007/s40484-020-0199-0

Zhao, S., Lin, Q., Ran, J., Musa, S.S., Yang, G., Wang, W., Lou, Y., Gao, D., Yang, L., He, D., Wang, M.H., 2020. Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China, from 2019 to 2020: A data-driven analysis in the early phase of the outbreak. Int. J. Infect. Dis. 92, 214-217. Doi: 10.1016/j.ijid.2020.01.050

Zhou, T., Liu, Q., Yang, Z., Liao, J., Yang, K., Bai, W., Lu, X., Zhang, W., 2020. Preliminary prediction of the basic reproduction number of the Wuhan novel coronavirus 2019-nCoV. J Evid Based Med 13 (1), 3-7. Doi: 10.1111/jebm.12376
Figure 1. The cumulative number of COVID-19 in the major epidemic areas of China
Figure 2. The trend of growth rate and R0
Figure 3. The latent class of $R_0$
Figure 4. The main prevention and control measures for COVID-19 in China
Table 1. The distribution of $R_0$ of COVID-19

| Province  | $R_0$ from SARS parameters | $R_0$ from COVID-19 parameters | $Z$  | $P$  |
|-----------|----------------------------|--------------------------------|------|------|
|           | Range | $P_{25}$ | $P_{50}$ | $P_{75}$ | Range | $P_{25}$ | $P_{50}$ | $P_{75}$ |      |      |
| Hubei     | 1.23-3.87 | 1.90 | 3.18 | 3.76 | 1.20-3.51 | 1.80 | 2.91 | 3.41 | -4.782 | <0.01 |
| Guandong  | 1.02-4.48 | 1.16 | 2.13 | 3.93 | 1.02-4.04 | 1.15 | 2.00 | 3.56 | -4.782 | <0.01 |
| Sichuan   | 1.07-3.32 | 1.28 | 2.01 | 2.94 | 1.06-3.03 | 1.25 | 1.90 | 2.71 | -4.782 | <0.01 |
| Anhui     | 1.04-4.43 | 1.24 | 2.44 | 4.03 | 1.03-3.99 | 1.22 | 2.26 | 3.65 | -4.782 | <0.01 |
| Shandong  | 1.24-2.51 | 1.53 | 1.99 | 2.36 | 1.21-2.33 | 1.47 | 1.88 | 2.20 | -4.782 | <0.01 |
| Jiangxi   | 1.03-4.76 | 1.21 | 2.49 | 4.34 | 1.03-4.28 | 1.19 | 2.31 | 3.92 | -4.782 | <0.01 |
| Zhejiang  | 1.01-5.10 | 1.08 | 1.85 | 4.25 | 1.01-4.57 | 1.07 | 1.75 | 3.84 | -4.782 | <0.01 |
| Henan     | 1.03-4.51 | 1.19 | 2.19 | 3.96 | 1.03-4.06 | 1.17 | 2.05 | 3.59 | -4.703 | <0.01 |
| Hunan     | 1.02-4.43 | 1.15 | 2.00 | 3.78 | 1.02-4.00 | 1.13 | 1.88 | 3.43 | -4.703 | <0.01 |
| Chongqing | 1.05-3.46 | 1.20 | 1.84 | 2.93 | 1.04-3.15 | 1.18 | 1.74 | 2.69 | -4.703 | <0.01 |
| Jiangsu   | 1.05-3.92 | 1.25 | 2.12 | 3.43 | 1.05-3.56 | 1.22 | 1.99 | 3.13 | -4.623 | <0.01 |
Table 2. The fitting index and latent class probability of the model

| $R_0$ from SARS parameters | Model | AIC  | BIC  | aBIC | Entropy | Class probability (%) |
|----------------------------|-------|------|------|------|---------|------------------------|
| 1                          | 317.51| 341.38| 160.72| -   | 1       |                         |
| 2                          | 72.44 | 108.65| -165.35| 1.00| 18.2/81.8|                         |
| 3                          | -92.09| -43.55| -410.89| 1.00| 27.3/63.6/9.1|                         |
| 4                          | -30.09| 30.79 | -429.90| 1.00| 27.3/31.8/31.8/9.1|                         |
| 5                          | -83.25| -10.04| -564.06| 1.00| 18.2/27.3/36.4/9.1/9.1|                         |
| $R_0$ from COVID-19 parameters | 1     | 229.47| 253.35| 72.69| -   | 1                      |
| 2                          | -16.12| 20.09 | -253.91| 1.00| 18.2/81.8|                         |
| 3                          | -181.98| -133.43| -500.78| 1.00| 27.3/63.6/9.1|                         |
| 4                          | -119.98| -59.10| -519.78| 1.00| 27.3/63.6/4.5/4.5|                         |
| 5                          | -149.15| -75.9 | -629.96| 1.00| 0/27.3/36.4/27.3/9.1|                         |