



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



ELSEVIER

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Evaluation of work resumption strategies after COVID-19 reopening in the Chinese city of Shenzhen: a mathematical modeling study



Lu Bai ^{a, i}, Haonan Lu ^{b, i}, Hailin Hu ^b, M. Kumi Smith ^c, Katherine Harripersaud ^d,
Veronika Lipkova ^e, Yujin Wen ^b, Xiuyan Guo ^b, Wei Peng ^b, Chenwei Liu ^b,
Mingwang Shen ^a, Alfred Chixiong Shen ^b, Lei Zhang ^{a, f, g, h, *}

^a China–Australia Joint Research Center for Infectious Diseases, School of Public Health, Xi'an Jiaotong University Health Science Center, Xi'an, Shaanxi, 710061, PR China

^b AI Application Research Center, Huawei Technologies Co., Ltd. Shenzhen, Guangdong, 518000, PR China

^c Division of Epidemiology and Community Health, University of Minnesota Twin Cities, Twin Cities, United States

^d ICAP, Mailman School of Public Health, Columbia University, New York, United States

^e Medical Sciences Division, University of Oxford, Oxford, United Kingdom

^f Melbourne Sexual Health Centre, Alfred Health, Melbourne, Australia

^g Central Clinical School, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, VIC, Australia

^h Department of Epidemiology and Biostatistics, College of Public Health, Zhengzhou University, Zhengzhou 450001, Henan, China

ARTICLE INFO

Article history:

Received 12 October 2020
Received in revised form
6 December 2020
Accepted 24 December 2020
Available online 3 February 2021

Keywords:

Coronavirus disease 2019 (COVID-19)
Shenzhen
Population mobility
Work resumption
Traffic resumption

ABSTRACT

Objectives: As China is facing a potential second wave of the epidemic, we reviewed and evaluated the intervention measures implemented in a major metropolitan city, Shenzhen, during the early phase of Wuhan lockdown.

Study design: Based on the classic SEITR model and combined with population mobility, a compartmental model was constructed to simulate the transmission of COVID-19 and disease progression in the Shenzhen population.

Methods: Based on published epidemiological data on COVID-19 and population mobility data from Baidu Qianxi, we constructed a compartmental model to evaluate the impact of work and traffic resumption on the epidemic in Shenzhen in various scenarios.

Results: Imported cases account for most (58.6%) of the early reported cases in Shenzhen. We demonstrated that with strict inflow population control and a high level of mask usage after work resumption, various resumptions resulted in only an insignificant difference in the number of cumulative infections. Shenzhen may experience this second wave of infections approximately two weeks after the traffic resumption if the incidence risk in Hubei is high at the moment of resumption.

Conclusion: Regardless of the work resumption strategy adopted in Shenzhen, the risk of a resurgence of COVID-19 after its reopening was limited. The strict control of imported cases and extensive use of facial masks play a key role in COVID-19 prevention.

© 2021 The Royal Society for Public Health. Published by Elsevier Ltd. All rights reserved.

Introduction

The coronavirus SARS-COV-2 pandemic had led to more than 31 million infections, and over 960,000 individuals died of the coronavirus disease 2019 (COVID-19), as of September 21st, 2020.¹ The COVID-19 epidemic broke out in early December 2019 in Wuhan,

the provincial capital city of Hubei in China. The virus proved to be capable of interpersonal transmission even in the absence of overt symptoms, which, in combination with increased travel before the Lunar New Year, resulted in its rapid spread to all 31 Chinese provinces.^{2–5} To curb the epidemic, the Wuhan authority imposed a strict metropolitan-wide 'lockdown' of Wuhan on Jan 23rd. During the 76 days (Jan 23rd to Apr 8th) lockdown, the operation of all public transportation in Wuhan was suspended, and all airport and railway stations were also temporarily closed.⁶ Within two days of the Wuhan lockdown, all 31 Chinese provinces and regions have launched the 'level 1 public health emergency response', which is the highest level of state of emergency.⁷ The lockdown has

* Corresponding author. Department of Epidemiology and Biostatistics, School of Public Health, Xi'an Jiaotong University Health Science Center, Xi'an, Shaanxi, 710061, PR China.

E-mail address: lei.zhang1@xjtu.edu.cn (L. Zhang).

ⁱ These authors contributed equally.

effectively limited the movement of the population and reduced the speed of spread of COVID-19 outside Hubei.^{2,9–10} Since the reopening of Wuhan city, the COVID-19 epidemic in China had been largely brought under control. As of September 21st, 2020, a total 85,291 cases were reported, and 4634 died of COVID-19 in Mainland China.¹ However, multiple small outbreaks have been reported across the country over the past three months, leading to a partial lockdown of the affected areas and vast cancellation of flights. As China is facing a potential second wave of the epidemic, we reviewed the intervention measures implemented in a major metropolitan city, Shenzhen, during the early phase of Wuhan lockdown. The past experiences may provide us with insights for future COVID-19 control and prevention.

Shenzhen was a megacity dominated by 8.5 million domestic migrants. This population accounted for 65% of its residents and formed the main labor force for Shenzhen's economy.¹¹ Before the implementation of 'level 1' response on January 23rd, Shenzhen's population outflow just peaked, with the total population outflow exceeding 9.5 million. Indeed, Shenzhen is a large city with high population mobility: during the period from January 1st to February 14th, 2020, the total population inflow to Shenzhen exceeded 8.4 million.¹² Because asymptomatic individuals can be infectious during the incubation period,^{5,13–15} the return of domestic migrants may serve as a potential source of new infections. Hence, it is possible that the population influx from other parts of China, especially Hubei, may have a significant impact on the epidemic in Shenzhen in the early stages after work resumption.¹⁶

Taking into consideration the high population mobility, we constructed a compartmental model to simulate the transmission of COVID-19 and disease progression in the Shenzhen population. Based on which, we aimed to evaluate the trend of the COVID-19 epidemic for various scenarios of work resumption strategies for the returning residents in Shenzhen.

Methods

Data sources

We collected early published epidemic data on COVID-19 cases in Shenzhen, which were obtained from the open data platform of Shenzhen Municipal Government.¹⁷ The population mobility data were retrieved from Baidu Qianxi with location-based services having nearly 9 billion location requests each day,¹⁸ which was also in the public domain.¹²

Model description

Definition of disease stages

Based on the classical epidemiological dynamic SEITR model,^{8,19} we proposed a M-SEITR model to evaluate the development of the epidemic, where 'M' stands for in-time population mobility correction (Fig. 1).²⁰ In the M-SEITR model, the population was divided into five compartments, which include susceptible individuals (*S*), individuals during the incubation period (*E*), infected but undiagnosed individuals (*I*), diagnosed individuals with treatment (*T*), recovered individuals (*R*), and death individuals (*D*). The total population size was denoted as *N*, ($N=S+E+I+T+R$).

The transmission of COVID-19 in the population

The schematic disease progression diagram is demonstrated in Fig. 1 (details in the Appendix). The model took into account the effects of facial mask usage $p(t)$ and interpersonal contact m per day on the COVID-19 epidemics. Specifically, we used a multinomial distribution to describe the transmission probability caused by

interpersonal contact, which depends on the number of daily interpersonal contacts and the probability of transmission per contact (β). Comparing with elsewhere in the world, the Chinese Government had developed guidelines for the use of masks and enforced a more strict facial mask-wearing practice, especially in public places and on public transports.^{8,21} At the initiation of the simulation at January 1st, where there were no confirmed cases reported in Shenzhen, we assumed the background facial mask rate to be zero (Fig. 1).

Impact of work resumption

We assumed that the probability of transmission decreased with the reduction of interpersonal contact and the increase in the use of facial masks. We assumed that the vast majority of citizens would maintain the habit of wearing masks until the end of the epidemic (even after work resumption). Furthermore, work resumption would increase the frequency of interpersonal contacts, which may further affect the trajectory of the epidemic. Importantly, we assumed that contact frequency m after work resumption would increase three-fold relative to the frequency of contact with family members before work resumption.²² And the various resumption of work ratio at different dates in the resumption strategies below affects the population mobility in Shenzhen. With the increase in the resumption of work ratio, the returning population in Shenzhen also increased, including people at different stages of disease (Appendix).

Simulation of population mobility

For population mobility, we assumed the population would return to Shenzhen after resumption in the same size and speed as they left the city before the strict control was implemented. We assumed that population mobility could affect three sub-populations, the susceptible individuals (*S*), the asymptomatic latent individuals (*E*), and undiagnosed infected individuals (*I*) (Fig. 1). The parameters and mathematical formulation for population mobility were listed in the Appendix. Imported cases first appeared in Shenzhen on January 4th, and the first local case of public transmission occurred on January 15th, considering the estimated incubation period of COVID-19 (3–7 days),^{11,15,23,24} we conservatively regard January 1st as the starting point of the Shenzhen epidemic.

Scenarios for evaluation

The epidemic situation in Hubei may impact on Shenzhen in two ways. First, because the number of confirmed cases in Hubei has increased substantially on February 12th because of the change of diagnostic criteria and the progress of patient admission,²⁵ it is likely that the number of latent infections among the Hubei travelers to Shenzhen in January might have been underestimated. The extent of control of the imported cases in Shenzhen in late January would impact substantially on the epidemic in Shenzhen. Second, the inflow of asymptomatic infections to Shenzhen after work resumption may be affected by the epidemic situation in Hubei.

We created four scenarios to reflect the potential intervention status in Shenzhen. Scenario 1 represents a prompt control of the inflow of the infected population from Hubei into Shenzhen in January and a low incidence risk in Hubei in March after work resumption. Scenario 2 represents a prompt control of the inflow of the infected population from Hubei in Shenzhen in January but a high incidence risk in Hubei in March after work resumption. Scenario 3 represents a delayed control of the inflow of the infected population from Hubei in Shenzhen in January and a low incidence

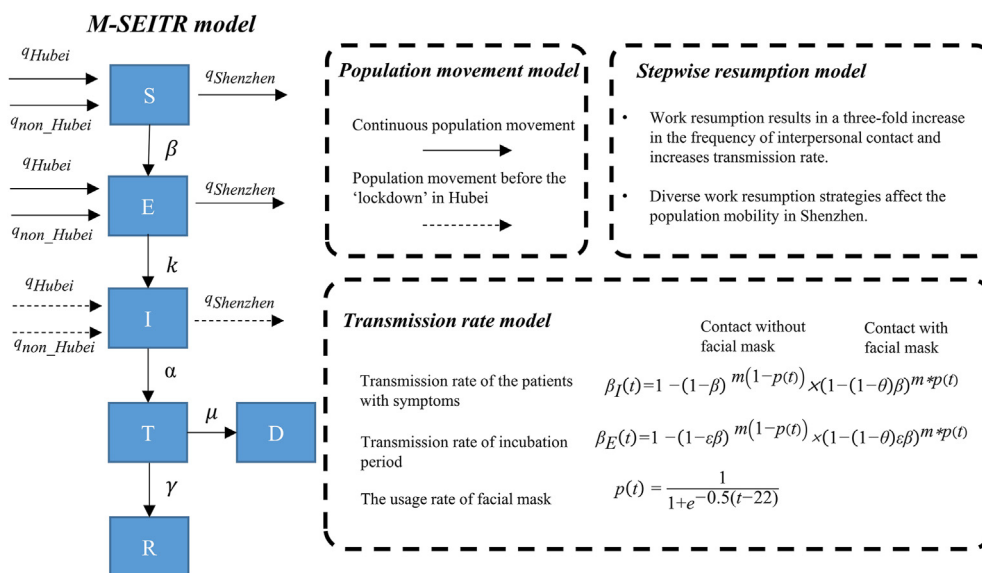


Fig. 1. Schematic diagram of M-SEITR model. On the basis of SEITR, the population migration, stepwise resumption of work strategies, and the transmission rate is simulated in detail. In the process of population movement, the model took into account the inflow to Shenzhen of Hubei travelers and non-Hubei travelers and the population outflow from Shenzhen, as well as the changing effect of the total population of Shenzhen at the same time. The transmission rate model combines the changes in the average number of interpersonal contacts per day and the effects of the facial mask usage.

risk in Hubei in March after work resumption. Scenario 4 represents a delayed control of the inflow of the infected population from Hubei in Shenzhen in January but a high incidence risk in Hubei in March after work resumption. The high and low incidence risk refers to the simulation of the rate of infection in Hubei with various level of decline in the epidemic trend.

Resumption strategies

To evaluate the possible impact of work resumption on the epidemic, we identified six stepwise resumption s in each scenario. These included (1) full resumption of work from February 10th; (2) scheme 1, a partial resumption of 57% on February 10th followed by a full resumption on February 17th; (3) scheme 2, a partial resumption of 51% on February 10th followed by a full resumption on February 17th; (4) scheme 3, a partial resumption of 51% on February 10th, then 63% on February 17th, followed by a full resumption on February 24th; (5) scheme 4, an increasing partial resumption of 39%, 51%, and 63% on February 10th, 17th, and 24th, respectively, followed by a full resumption on March 2nd; (6) scheme 5, a partial resumption of 57% and 74% on February 10th and 17th, respectively, followed by a full resumption on February 24th. The calculation of the partial resumption is based on the type of industry, immediate urgency for the resumption and their impact on the spread of the epidemic. In general, industries related to people's daily necessities were prioritized. These were followed by industries that were essential but allowed for 'work from home', then industries that may be resumed in the near future, and those can be further delayed. The full explanation of the resumption schemes was listed in the Appendix (Tables S1 and S2).

Model calibration

We calibrated the model parameters based on the of confirmed cases of COVID-19 published in by Shenzhen Center for Disease Control (Appendix). Overall, the calibrated model demonstrated good consistency between the model output and the reported number of imported cases.

Results

Of 406 confirmed cases that were reported in Shenzhen, 238 cases (58.6%) were imported. Of these imported cases, 153 cases (37.7%) were from Hubei. There were 105 local cases due to household transmission and 63 due to public contacts, accounting for 25.9% and 15.5% of all reported cases. Table 1 demonstrated the composition of COVID-19 cases in Shenzhen.

We predicted the cumulative number of infected cases for the six resumption strategies based on the four intervention scenarios in Shenzhen. When a prompt control of the inflow of the infected population was in place, and incidence risk in Hubei was low (scenario 1), full work resumption from February 10th would result in 68 additional infected cases between February 10th and April 30th, and the cumulative infected cases would reach 456 (453–458) by April 30th. For the other five stepwise resumption schemes in scenario 1, the cumulative number of infected individuals was reduced compared with that of full work resumption scheme, but the difference was small (3–5 fewer cases by April 30th). By contrast, when a prompt control of inflow of infected population was in place but the incidence risk in Hubei was high (scenario 2), the number of cumulative infected cases would reach 542 (540–544) in the event of full work resumption. However, if the control of the infected population from Hubei in Shenzhen in January was delayed, full resumption of work would result in a much higher number of cases by April 30th (scenario 3, low incidence risk in Hubei: 922 [848–995]; scenario 4, high incidence risk in Hubei: 1044 [936–1153]). In scenarios 2, 3, and 4, the differences between work resumption schemes were small, and by the end of April, the cumulative number of infected cases only differed by 2–4, 41–73, and 54–99, respectively (Table S4).

The estimated number of individuals who were infected but undiagnosed demonstrated a similar trend across all four scenarios, reaching a peak (98–158 cases) around the end of January, before gradually declining. The traffic resumption in Hubei province may lead to a second but significantly smaller peak (24–26 cases) if Hubei remains a high incidence risk in March. After the second peak, the trend would continue to decline to zero (Fig. 2).

Table 1
The number of reported cases of COVID-19 in Shenzhen 3 weeks after Wuhan's lockdown.

Case type		The number of cases	Proportion
Imported cases ^a	Hubei travelers	153	37.7%
	Non-Hubei travelers	85	20.9%
Local household transmission		105	25.9%
Local public transmission		63	15.5%
Total		406	—

^a If a family group arrived Shenzhen and more than one member was diagnosed positive, then only one case was regarded as 'imported case' and the rest were local household transmission cases.

Discussion

Our study demonstrated that imported cases account for most (58.6%) of all reported cases in Shenzhen. In particular, imported cases from Hubei account for 37.7%. If Shenzhen maintains strict control measures with regard to the inflow population, and its citizens maintain a high level of mask usage even after the resumption of operations, the epidemic will gradually subside, with few differences between the proposed resumption schemes. If intercity travel is restored when Hubei still has a high incidence risk, Shenzhen may experience a second wave of infections.

Our analysis indicates that the COVID-19 epidemic in Shenzhen would mainly result from imported cases and household transmission, with the local public transmission being relatively limited.²⁶ Notably, only one-quarter of the cases were due to

household transmission, which stands in sharp contrast to the 56–61% in Hubei province.^{1,27} As the virus is highly contagious and protective measures in a household setting are usually limited, the chance of transmission due to an asymptomatic infected household member is very high. The low percentage of household transmission indicates that early public health measures in Shenzhen have been effective. In particular, strict temperature monitoring, timely isolation, contact tracing and treatment for confirmed cases seems to have played a major role.²⁸

We found that different work resumption strategies have little impact on the overall trajectory of the epidemic in Shenzhen. This may be for a number of reasons. First, because the number of undiagnosed infected cases in Shenzhen was small and the epidemic was well controlled in its early phase, the impact of various resumption strategies makes little difference to the epidemic.

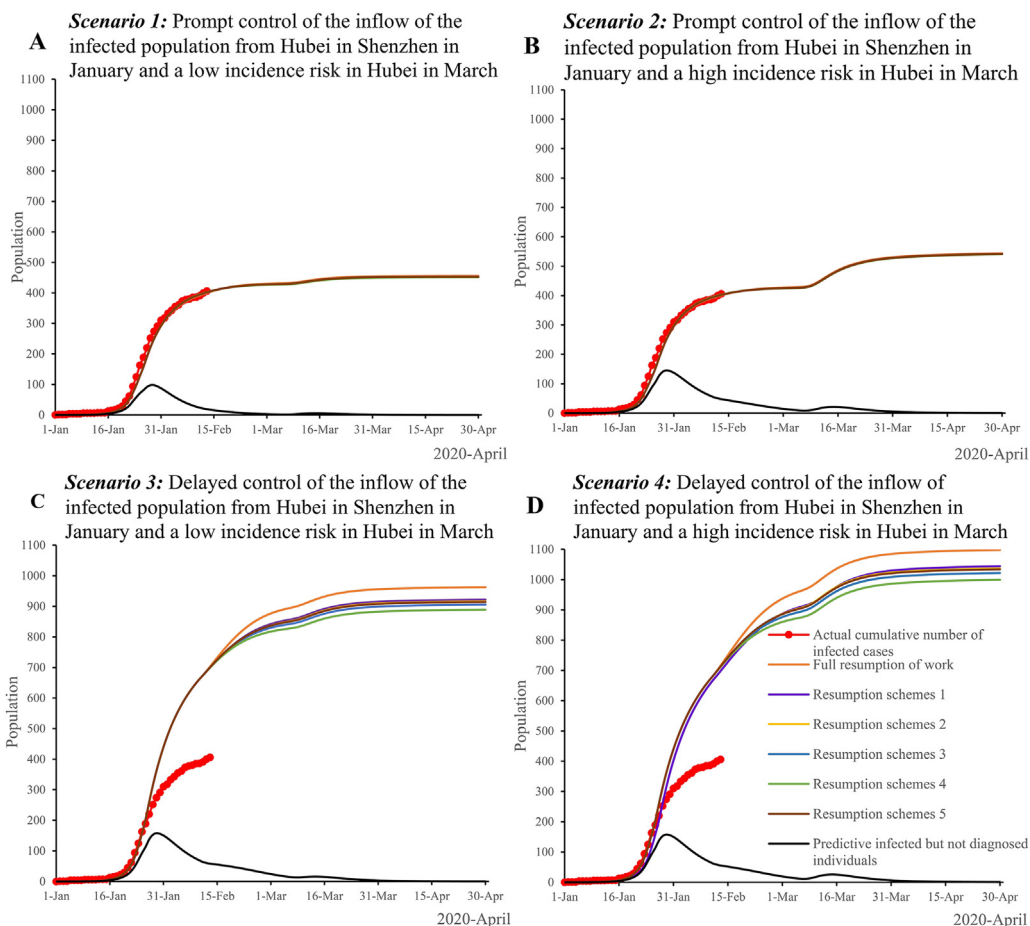


Fig. 2. Under the four scenarios of the epidemic hypothesis of Shenzhen and the six resumption s, the changing trend of the predictive cumulative number of infected cases (C) and the predicted number of infected but undiagnosed individuals (I) in Shenzhen. (1) Full resumption of work from February 10th; (2) 1, a partial resumption of 57% on February 10th followed by a full resumption on February 17th; (3) 2, a partial resumption of 51% on February 10th followed by a full resumption on February 17th; (4) 3, a partial resumption of 51% on February 10th, then 63% on February 17th, followed by a full resumption on February 24th; (5) 4, an increasing partial resumption of 39%, 51% and 63% on February 10th, 17th, and 24th, respectively, followed by a full resumption on March 2nd; (6) 5, a partial resumption of 57% and 74% on February 10th and 17th, respectively, followed by a full resumption on February 24th.

Second, as facial masks were widely used, including asymptomatic individuals, an increase in the frequency of interpersonal contacts caused by work resumption does not effectively increase the transmission of SARS-CoV-2, suggesting that the ongoing personal protective measures were crucial to the process of the city reopening.²⁹

Our analysis showed that if Hubei had restored traffic in early March, Shenzhen might have experienced the second wave of the outbreak at a later point that month. However, the number of imported cases is small, and the threat is limited. The Shenzhen government has imposed strict resumption strategies that encourage business to implement altered off-peak dining, such as reducing the frequency and scale of meetings and minimizing staff gatherings.²⁸ These measures are key in preventing a second outbreak in Shenzhen.

This study has several limitations. First, the model did not take into account the spread caused by the use of public transportation (e.g. subway and buses); consequently, the risk of transmission in public spaces may have been underestimated. Second, we modeled the population mobility model based on data from Baidu Qianxi, which may not fully account for the actual movement of the population. Third, our model did not take into consideration of overseas imported cases. Besides, we did not take into account the human behaviors (e.g. social distancing and hands washing) and may overestimate the COVID-19 epidemic in Shenzhen. Yet this allows our evaluation of prevention measures to be more conservative.

In conclusion, regardless of the work resumption strategy adopted in Shenzhen, the risk of a resurgence of COVID-19 after its reopening was limited. The strict control of imported cases and extensive use of facial masks play a key role in COVID-19 prevention.

Author statements

Acknowledgments

The authors are grateful to Feng Sha, Ling Yin, Ruxin Wang, and Ye Li from the Digital Research Institute of Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences for calculating and providing the resumption of work ratio.

Ethical approval

Not applicable, as no patient personal information is involved in this study.

Funding

This work is supported by a Research Grant from the Bill & Melinda Gates Foundation. LZ is supported by the National Natural Science Foundation of China (Grant number: 81950410639); Outstanding Young Scholars Support Program (Grant number: 3111500001); Xi'an Jiaotong University Basic Research and Profession Grant (Grant number: xtr022019003, xzy032020032); Epidemiology modeling and risk assessment (Grant number: 20200344) and Xi'an Jiaotong University Young Scholar Support Grant (Grant number: YX6J004). MS is supported by the National Natural Science Foundation of China (Grant number: 11801435); China Postdoctoral Science Foundation (Grant number: 2018M631134, 2020T130095ZX); the Fundamental Research Funds for the Central Universities (Grant number: xjh012019055, xzy032020026); Natural Science Basic Research Program of

Shaanxi Province (Grant number: 2019JQ-187); Xi'an Special Science and Technology Projects on Prevention and Treatment of Novel Coronavirus Pneumonia Emergency (Grant number: 20200005YX005); Science Foundation for COVID-19 of Xi'an Jiaotong University Health Science Center and Qinnong Bank (Grant number: 2008124); Zhejiang University special scientific research fund for COVID-19 prevention and control (Grant number: 2020XGZX056).

This work is supported by the Bill & Melinda Gates Foundation.

Competing interests

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Availability of data and materials

The data that support the findings of this study are available from the open data platform of Shenzhen Municipal Government¹⁷ and the population mobility data were retrieved from Baidu Qianxi,¹⁸ which was also in the public domain¹².

Disclaimer

The funding agencies had no involvement in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

Authors' contributions

HL, HH, MS, ACS, and LZ conceived and designed the study. HL, HH, YW, XG, WP, and CL analyzed the data, carried out the analysis, and performed numerical simulations. LB wrote the first draft of the manuscript. MKS, KH, VL, and YW critically read and revised the manuscript. All authors contributed to writing the article and agreed with manuscript results and conclusions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.puhe.2020.12.018>.

References

1. World Health Organization. *Report of the WHO-China joint mission on coronavirus disease 2019 (COVID-19)*. 2020.
2. Ai S, Zhu G, Tian F, Li H, Gao Y, Wu Y, Liu Q, Lin H. Population movement, city closure and spatial transmission of the 2019-nCoV infection in China. *medRxiv* 2020. <https://doi.org/10.1101/2020.02.04.20020339>.
3. Boldog P, Tekeli T, Vizi Z, Denes A, Bartha F, Rost G. Risk assessment of novel coronavirus 2019-nCoV outbreaks outside China. *medRxiv* 2020. <https://doi.org/10.1101/2020.02.04.20020503>.
4. Cohen J, Normile D. New SARS-like virus in China triggers alarm. *Science* 2020;**367**:234–5.
5. Wu P, Hao X, Lau EHY, Wong JY, Leung KSM, Wu JT, Cowling BJ, Leung GM. Real-time tentative assessment of the epidemiological characteristics of novel coronavirus infections in Wuhan, China, as at Jan 22nd 2020. *Euro Surveill* 2020;**25**:2000044.
6. Shen M, Peng Z, Guo Y, Rong L, Li Y, Xiao Y, Zhuang G, Zhang L. Assessing the effects of metropolitan-wide quarantine on the spread of COVID-19 in public space and households. *Int J Infect Dis* 2020;**22**(2):69–71.
7. Fenghuang News. *All provinces, municipalities and autonomous regions across the country have launched a first-level response*. 2020.
8. Shen M, Zu J, Fairley CK, Pagan JA, Ferket B, Liu B, Yi SS, Chambers E, Li G, Guo Y, Rong L, Xiao Y, Zhuang G, Zebrowski A, Carr BG, Li Y, Zhang L. Effects of New

- York's executive order on face mask use on COVID-19 infections and mortality: A modeling study. *J Urban Health* 2021, in press.
9. Chinazzi M, Davis JT, Ajelli M, Gioannini C, Litvinova M, Merler S, Pastore y Piontti A, Mu K, Rossi L, Sun K, Viboud C, Xiong X, Yu H, Halloran ME, Longini IM, Vespignani A. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science* 2020:eaba9757.
 10. Zhou X, Wu Z, Yu R, Cao S, Fang W, Jiang Z, Yuan F, Yan C, Chen D. Modelling-based evaluation of the effect of quarantine control by the Chinese government in the coronavirus disease 2019 outbreak. *medRxiv* 2020. <https://doi.org/10.1101/2020.03.03.20030445>.
 11. Chen J. Pathogenicity and transmissibility of 2019-nCoV—a quick overview and comparison with other emerging viruses. *Microb Infect* 2020;**22**(2):69–71.
 12. Baidu Map Smart Eyes. *Baidu migration*. 2020. <https://qianxi.baidu.com> (accessed February 14 2020).
 13. Chan JF-W, Yuan S, Kok K-H, To KK-W, Chu H, Yang J, Xing F, Liu J, Yip CC-Y, Poon RW-S, Tsoi H-W, Lo SK-F, Chan K-H, Poon VK-M, Chan W-M, Ip JD, Cai J-P, Cheng VC-C, Chen H, Hui CK-M, Yuen K-Y. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet* 2020;**395**:514–23.
 14. Yu P, Zhu J, Zhang Z, Han Y. A familial cluster of infection associated with the 2019 novel coronavirus indicating possible person-to-person transmission during the incubation period. *J Infect Dis* 2020;**221**(11):1757–61.
 15. Gao W, Li L. Advances on presymptomatic or asymptomatic carrier transmission of COVID-19. *Chin J Epidemiol* 2020;**41**.
 16. Zhang L, Tao Y, Wang J, Ong JJ, Tang W, Zou M, Bai L, Ding M, Shen M, Zhuang G, Fairley CK. Early characteristics of the COVID-19 outbreak predict the subsequent size. *Int J Infect Dis* 2020;**97**:219–24.
 17. Shenzhen Municipal Government, China. *Data open platform of shenzhen municipal government*. 2020.
 18. Lai S, Bogoch I, Ruktanonchai N, Watts A, Lu X, Yang W, Yu H, Khan K, Tatem AJ. Assessing spread risk of Wuhan novel coronavirus within and beyond China, January–April 2020: a travel network-based modelling study. *medRxiv* 2020. <https://doi.org/10.1101/2020.02.04.20020479>.
 19. Shen M, Peng Z, Xiao Y, Zhang L. Modeling the epidemic trend of the 2019 novel coronavirus outbreak in China. *Innovation (N Y)* 2020;**1**(3):100048.
 20. Brockmann D, Helbing D. The hidden geometry of complex, network-driven contagion phenomena. *Science* 2013;**342**:1337–42.
 21. Chinese Center for Disease Control and Prevention. *Guidelines for the protection of people with different risks of COVID-19*. 2020.
 22. Read JM, Lessler J, Riley S, Wang S, Tan LJ, Kwok KO, Guan Y, Jiang CQ, Cummings DAT. Social mixing patterns in rural and urban areas of southern China. *Proc Biol Sci* 2014;**281**. <https://doi.org/10.1101/20140268-20140268>.
 23. Chinese Center for Disease Control and Prevention. *Report about COVID-19*. 2020.
 24. Backer JA, Klinkenberg D, Wallinga J. Incubation period of 2019 novel coronavirus (2019-nCoV) infections among travellers from Wuhan, China, 20–28 January 2020. *Euro Surveill* 2020;**25**:2000062.
 25. Sina News. *The reform of diagnostic criteria has resulted in 14,800 new cases being confirmed in Hubei in one day*. 2020.
 26. Guan W-j, Ni Z-y, Hu Y, Liang W-h, Ou C-q, He J-x, Liu L, Shan H, Lei C-l, Hui DSC, Du B, Li L-j, Zeng G, Yuen K-y, Chen R-c, Tang C-l, Wang T, Chen P-y, Xiang J, Li S-y, Wang J-l, Liang Z-j, Peng Y-x, Wei L, Liu Y, Hu Y-h, Peng P, Wang J-m, Liu J-y, Chen Z, Li G, Zheng Z-j, Qiu S-q, Luo J, Ye C-j, Zhu S-y, Zhong N-s. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med* 2020;**382**(18):1708–20.
 27. Qin X, Qiu S, Yuan Y, Zong Y, Tuo Z, Li J, Liu J. Clinical characteristics and treatment of patients infected with COVID-19 in shishou, China. *SSRN* 2020.
 28. Cao Z, Zhang Q, Lu X, Pfeiffer D, Wang L, Song H, Pei T, Jia Z, Zeng DD. Incorporating human movement data to improve epidemiological estimates for 2019-nCoV. *medRxiv* 2020. <https://doi.org/10.1101/2020.02.07.20021071>.
 29. Zhang L, Tao Y, Shen M, Fairley CK, Guo Y. Can self-imposed prevention measures mitigate the COVID-19 epidemic? *PLoS Med* 2020;**17**:e1003240.