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Forecasting the Domestic Infection and Spread of the 2019-nCoV Outbreak

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Abstract: **Due to the outbreak of 2019-nCoV in Wuhan, China, the infection had spread out worldwide in a dramatic speed. Through the SEIR model, this paper managed to forecast the domestic infection and spread of the coronavirus. Considering the number of susceptible, latent, infectious, and removed individuals, we estimated the R0 for Wuhan, Chongqing, Beijing, Shanghai, Guangzhou, and Shenzhen, along with a 95% confident interval.**

Keywords: **2019-nCoV, forecast, SEIR.**

1. INTRODUCTION

In December, 2019, some patients infected by an unknown disease had been diagnosed in Wuhan, China. Soon 27 infections were discovered and this new virus is known as the zoonotic 2019 novel coronavirus (2019-nCoV). Immediately called attention by the virus, Wuhan government implements precaution to restrict further infection. Unfortunately China is experiencing the Spring Festival travel rush, so people are having abnormal mobility during January and February. A significant infection boom occurred, and the infected population skyrocket.

According to the National Health Commission of China, until February 27^{th}, reported by the Production and Construction Group from 31 provinces and Xinjiang province, 39919 cases had been presently confirmed, including 7952 cases of serious conditions. 2788 cases had been recorded as cumulative death cases, and 36117 cases as cumulative recurrence. Cumulatively 78824 confirmed cases had been reported. Recently the suspected case number was 2308. 656084 cases were traced as suspected cases, while 65225 cases had been in close observation (figure 1).

For Hubei province especially, resently 36829 confirmed cases had been recorded, including 7633 cases of serious condition. 26403 cases of cumulative recurrence, 2782cases of cumulative death, and 65914 cases of cumulative confirmed were recorded (National Health Commission of the People's Republic of China, 2020).

In this article, we are going to forecast the infected case spread using modeling. From a public health control viewpoint, we will forecast the probable course of spread domesticexssssssw1q`ally and internationally, first by assuming similar transmissibility as the initial phase in Wuhan, then account the possible cases augment domestically. Subsequently an argument based on virus precaution will be made, accompanied by policies that had been implemented. Considering the time period this paper had been made, a follow-up significant test will examine the validity of this study.

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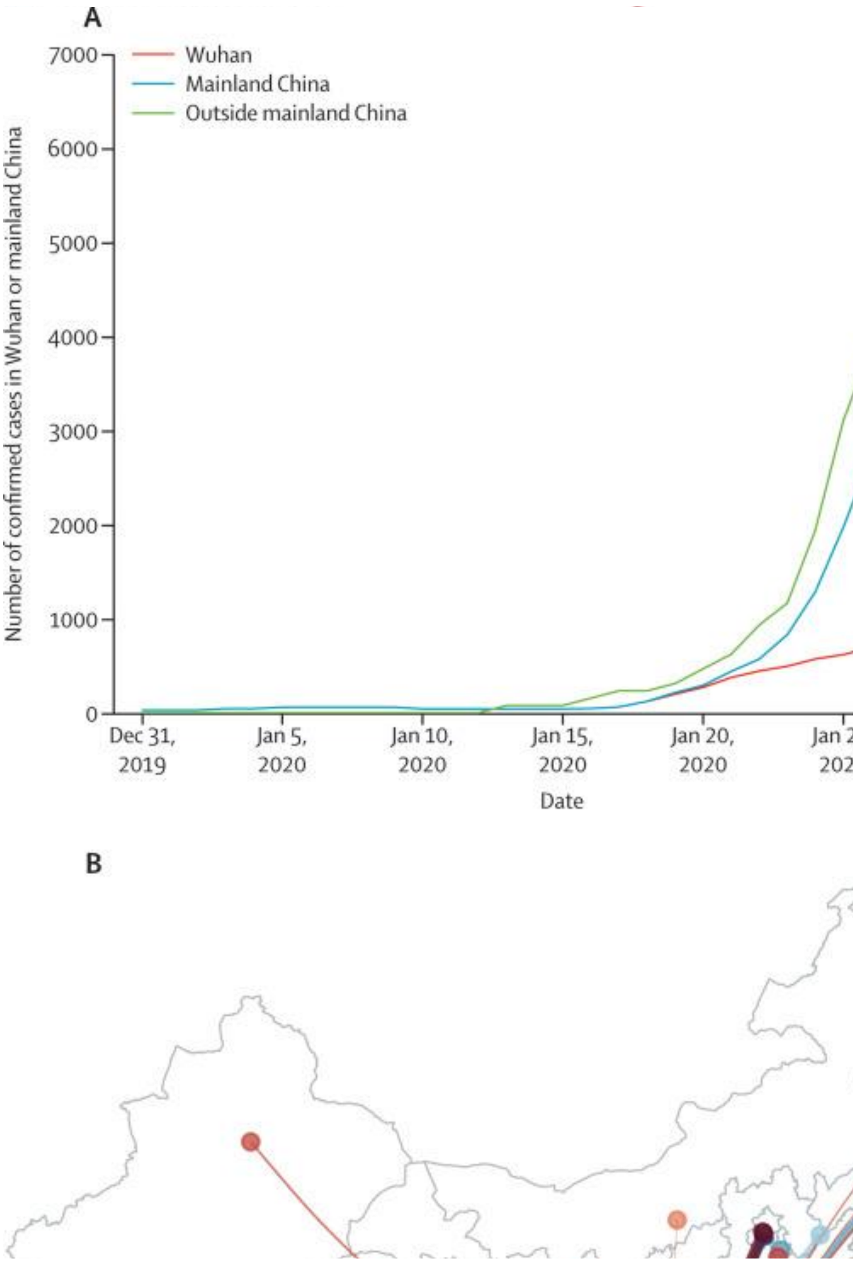

Figure 1: the infection cases in Wuhan, mainland of China, and outside mainland of China (Wu, Leung, 2020)

2. METHOD

The data examined in this research were retrieved from inferences published by the National Health Commission of People's Republic of China, from January 11th to February 27th. Based on a population of 112.12 millions, we would also consult to the daily transportation inflow and outflow population (Baidu, 2019).

According to the announcement published by Huhan gorvernment institution, only one flight for each air line is allowed each week for each airline.

We used the following susceptible-exposed-infectious-recovered (SEIR) model to simulate the Wuhan epidemic since it was established in December, 2019:

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$$\frac{dS(t)}{dt} = -\frac{S(t)}{N}\left(\frac{R_0}{D_I}I(t) + z(t)\right) + L_{I,W} + L_{C,W}(t) - \left(\frac{L_{W,I}}{N} + \frac{L_{W,C}(t)}{N}\right)S(t)$$

$$\frac{dE}{dt} = \frac{S(t)}{N}\left(\frac{R_0}{D_I}I(t) + z(t)\right) - \frac{E(t)}{D_E} - \left(\frac{L_{W,I}}{N} + \frac{L_{W,C}(t)}{N}\right)E(t)$$

$$\frac{dI(t)}{dt} = \frac{E(t)}{D_E} - \frac{I(t)}{D_I} - \left(\frac{L_{W,I}}{N} + \frac{L_{W,C}(t)}{N}\right)I(t)$$

where *S(t)*, *E(t)*, *I(t)*, and *R(t)* were the number of susceptible, latent, infectious, and removed individuals at time *t*; *D*E and *D*I were the mean latent (assumed to be the same as incubation) and infectious period (equal to the serial interval minus the mean latent period; *R*0 was the basic reproductive number; *z(t)* was the zoonotic force of infection equal to 86 cases per day in the baseline scenario before market closure on Jan 1, 2020, and equal to 0 thereafter. The cumulative number of infections and cases that had occurred in Greater Wuhan up to time *t* was obtained from the SEIR model.

We estimated *R*0 using Markov Chain Monte Carlo methods with Gibbs sampling and non-informative flat prior. For a given *R*0 from the resulting posterior distribution, we used the same SEIR model to estimate the corresponding outbreak size in Wuhan and the probability distribution of the number of cases that had been exported domestically to other cities in mainland China (on the basis of the destination distribution in our calibrated Tencent mobility data). Point estimates were presented using posterior means, and statistical uncertainty was presented using 95% confidence intervals (CIs).

We extended the above SEIR model into a SEIR-metapopulation model to simulate the spread of 2019-nCoV across mainland China, assuming the transmissibility of 2019-nCoV was similar across all cities.(Atmon, 2019, p.252)

The movements of individuals between more than 300 prefecture-level cities were modelled using the daily average traffic volumes in our calibrated Tencent mobility data. Given that 2019-nCoV has caused widespread outbreak awareness not only among public health professionals, but also among the general public in China and other countries, the transmissibility of the epidemic might be reduced compared with its nascent stage at Wuhan because of community-wide social distancing measures and other non-pharmaceutical interventions. Previous studies suggested that non-pharmaceutical interventions might be able to reduce influenza transmission by up to 50%.

As such, we simulated local epidemics across mainland China assuming that the transmissibility of 2019-nCoV was reduced by 0%, 25%, and 50% after Wuhan was quarantined on Jan 23, 2020. The epidemics would fade out if transmissibility could be reduced by 1–1/*R*0. Furthermore, we considered 50% reduction in inter-city mobility. Finally, we hypothesised that citywide population quarantine at Wuhan had negligible effect on the epidemic trajectories of the rest of the country and tested this hypothesis by making the extreme assumption that all inbound and outbound mobility at Wuhan were eliminated indefinitely on Jan 23, 2020.

3. RESULTS

Figure 2 summarises our estimates of the basic reproductive number *R*0 and the outbreak size of 2019-nCoV in Wuhan as of Jan 25, 2020. In our baseline scenario, we estimated that *R*0 was 2.68 (95% CI 2.47–2.86) with an epidemic doubling time of 6.4 days (95% CI 5.8–7.1). We estimated that 75815 individuals (95% CI 37304–130330) individuals had been

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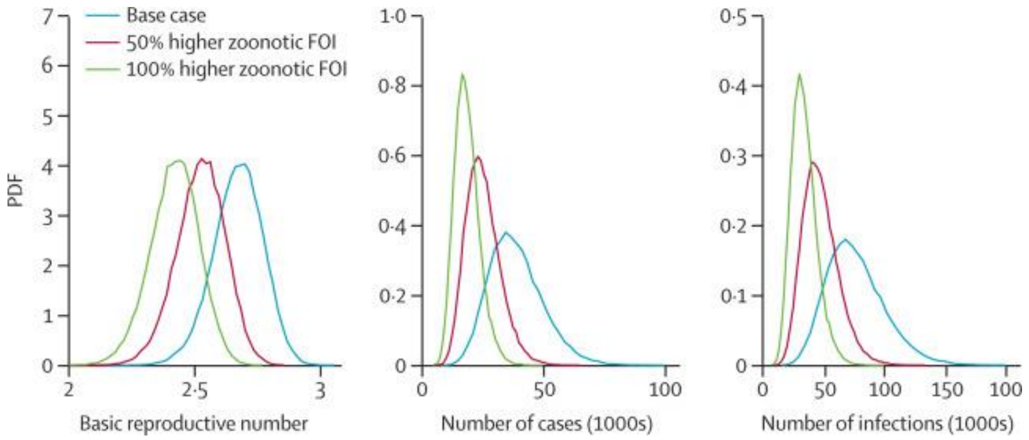
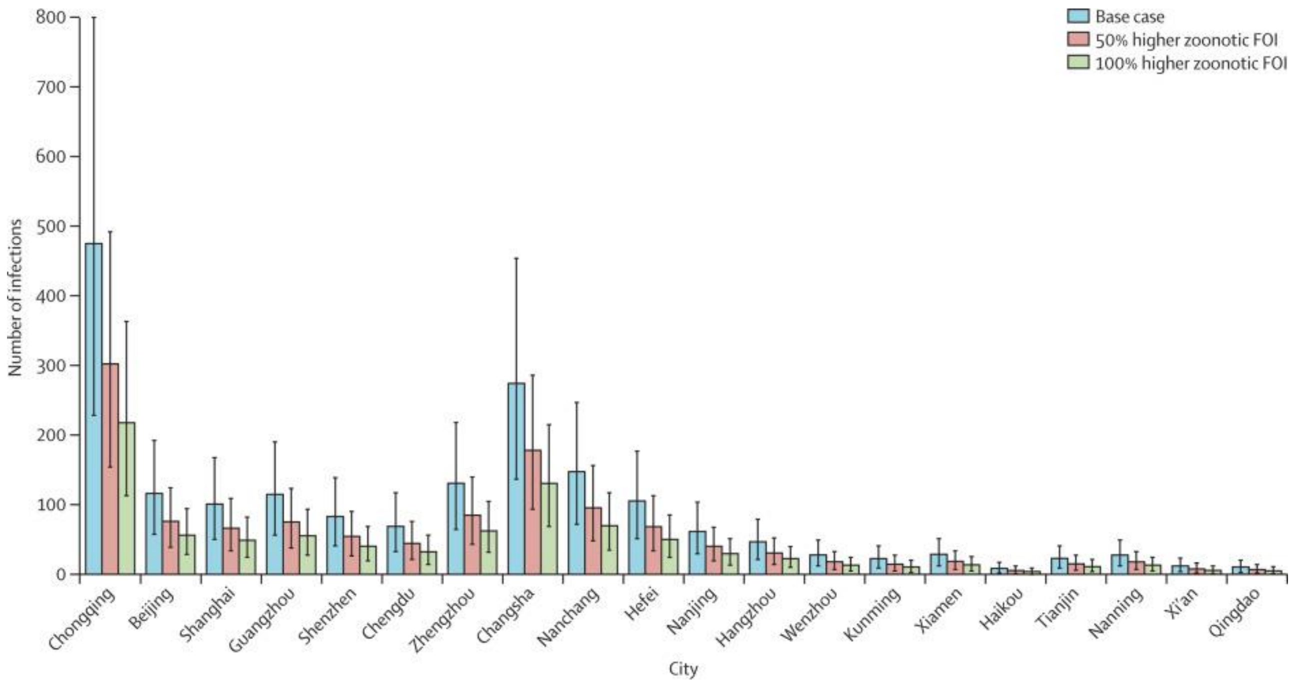
infected in Greater Wuhan as of Jan 25, 2020. We also estimated that Chongqing, Beijing, Shanghai, Guangzhou, and Shenzhen, had imported 461 (227–805), 113 (57–193), 98 (49–168), 111 (56–191), and 80 (40–139) infections from Wuhan, respectively (figure 3). Beijing, Shanghai, Guangzhou, and Shenzhen were the mainland Chinese cities that together accounted for 53% of all outbound international air travel from China and 69% of international air travel outside Asia, whereas Chongqing is a large metropolis that has a population of 32 million and very high ground traffic volumes with Wuhan. Substantial epidemic take-off in these cities would thus contribute to the spread of 2019-nCoV within and outside mainland China.





If the zoonotic force of infection that initiated the Wuhan epidemic was 50% and 100% higher than the baseline scenario value, then *R*0 would be 2.53 (95% CI 2.32–2.71) and 2.42 (2.22–2.60), respectively. The corresponding estimate of the number of infections in Wuhan would be 38% and 56% lower than baseline. The number of exported cases and infections in Chongqing, Beijing, Shanghai, Guangzhou, and Shenzhen would be similarly reduced in magnitude.

For Wuhan, Chongqing, Beijing, Shanghai, Guangzhou, and Shenzhen with a $R0$ of 2.68, assume 0%, 25%, or 50% decrease in transmissibility across all cities, together with 0% or 50% reduction in inter-city mobility after Wuhan was quarantined on Jan 23, 2020. The epidemics would fade out if transmissibility was reduced by more than $1–1/R0$=63%. Our estimates suggested that a 50% reduction in inter-city mobility would have a negligible effect on epidemic dynamics. We estimated that if there was no reduction in transmissibility, the Wuhan epidemic would peak around April, 2020, and local epidemics across cities in mainland China would lag by 1–2 weeks. If transmissibility was reduced by 25% in all cities domestically, then both the growth rate and magnitude of local epidemics would be substantially reduced; the epidemic peak would be delayed by about 1 month and its magnitude reduced by about 50%. A 50% reduction in transmissibility would push the viral reproductive number to about 1.3, in which case the epidemic would grow slowly without peaking during the first half of 2020. However, our simulation suggested that wholesale quarantine of population movement in Greater Wuhan would have had a negligible effect on the forward trajectories of the epidemic because multiple major Chinese cities had already been seeded with more than dozens of infections each (results not shown because they are visually indistinguishable from figure 4). The probability that the chain of transmission initiated by an infected case would fade out without causing exponential epidemic growth decreases sharply as $R0$ increases.

As such, given the substantial volume of case importation from Wuhan, local epidemics are probably already growing exponentially in multiple major Chinese cities. Given that Beijing, Shanghai, Guangzhou, and Shenzhen together accounted for more than 50% of all outbound international air travel in mainland China, other countries would likely be at risk of experiencing 2019-nCoV epidemics during the first half of 2020.

4. DISCUSSION

During the period of an epidemic when human-to-human transmission is established and reported case numbers are rising exponentially, nowcasting and forecasting are of crucial importance for public health planning and control domestically and internationally.

In this study, we have estimated the outbreak size of 2019-nCoV thus far in Wuhan and the probable extent of disease spread to other cities domestically. Our findings suggest that independent self-sustaining human-to-human spread is already present in multiple major Chinese cities, many of which are global transport hubs with huge numbers of both inbound and outbound passengers (eg, Beijing, Shanghai, Guangzhou, and Shenzhen).

Therefore, in the absence of substantial public health interventions that are immediately applied, further international seeding and subsequent local establishment of epidemics might become inevitable. On the present trajectory, 2019-nCoV could be about to become a global epidemic in the absence of mitigation. Nevertheless, it might still be possible to secure containment of the spread of infection such that initial imported seeding cases or even early local transmission does not lead to a large epidemic in locations outside Wuhan. To possibly succeed, substantial, even draconian measures that limit population mobility should be seriously and immediately considered in affected areas, as should strategies to drastically reduce within-population contact rates through cancellation of mass gatherings, school closures, and instituting work-from-home arrangements, for example. Precisely what and how much should be done is highly contextually specific and there is no one-size-fits-all set of prescriptive interventions that would be appropriate across all settings. Should containment fail and local transmission is established, mitigation measures according to plans that had been drawn up and executed during previous major outbreaks, such as those of SARS, MERS, or pandemic influenza, could serve as useful reference templates.

The overriding epidemiological priority to inform public health control would be to compile and release a line list of suspected, possible, probable, and confirmed cases and close contacts that is updated daily and linked to clinical outcomes and laboratory test results. A robust line list is essential for the generation of accurate and precise epidemiological parameters as inputs into transmission models to inform situational awareness and optimising the responses to the epidemic.

Additionally, given the extent of spread and level of public concern it has already generated, the clinical spectrum and severity profile of 2019-nCoV infections needs rapid ascertainment by unbiased and reliable methods in unselected samples of cases, especially those with mild or subclinical presentations.

The modelling techniques that we used in this study are very similar to those used by other researchers who are working towards the same goal of characterising the epidemic dynamics of 2019-nCoV (Zhanwei Du, University of Texas at Austin, personal communication).

The consensus on our methodology provides some support for the validity of our nowcasts and forecasts. An additional strength of our study is that our model is parameterised with the latest mobility data from OAG and Tencent. Nonetheless, our study has several major limitations. First, we assumed that travel behaviour was not affected by disease status and that all infections eventually have symptoms (albeit possibly very mild). We would have underestimated the outbreak size in Greater Wuhan if individuals with increased risk of infection (eg, confounded by socioeconomic status) were less likely to travel internationally or if the proportion of asymptomatic infections were substantial. Second, our estimate of transmissibility and outbreak size was somewhat sensitive to our assumption regarding the zoonotic mechanism that initiated the epidemic at Wuhan. However, our overall conclusion regarding the extent of case exportation in major Chinese cities would remain the same even for our lowest estimate of transmissibility (figure 3). Third, our epidemic forecast was based on inter-city mobility data from 2019 that might not necessarily reflect mobility patterns in 2020, especially in the presence of current public vigilance and response regarding the health threat posed by 2019-nCoV . Fourth, little is known regarding the seasonality of coronavirus transmission. If 2019-nCoV, similar to influenza, has strong seasonality in its transmission, our epidemic forecast might not be reliable.

Identifying and eliminating the zoonotic source remains an important task to prevent new animal-to-human seeding events. The renewal of a complete ban on market trading and sale of wild game meat in China on Jan 26 can provide only temporary suspension of demand, even if completely adhered to.

Vaccine platforms should be accelerated for real-time deployment in the event of a second wave of infections. Above all, for health protection within China and internationally, especially those locations with the closest travel links with major Chinese ports, preparedness plans should be readied for deployment at short notice, including securing supply chains of pharmaceuticals, personal protective equipment, hospital supplies, and the necessary human resources to deal with the consequences of a global outbreak of this magnitude.

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