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Research article

Data-driven assessment of immune evasion and dynamic Zero-COVID policy on fast-spreading Omicron in Changchun

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Abstract: Due to its immune evasion capability, the SARS-CoV-2 Omicron variant was declared a variant of concern by the World Health Organization. The spread of Omicron in Changchun (i.e., the capital of Jilin province in northeast of China) during the spring of 2022 was successfully curbed under the strategy of a dynamic Zero-COVID policy. To evaluate the impact of immune evasion on vaccination and other measures, and to understand how the dynamic Zero-COVID measure stopped the epidemics in Changchun, we establish a compartmental model over different stages and parameterized the model with actual reported data. The model simulation firstly shows a reasonably good fit between our model prediction and the data. Second, we estimate the testing rate in the early stage of the outbreak to reveal the real infection size. Third, numerical simulations show that the coverage of vaccine immunization in Changchun and the regular nucleic acid testing could not stop the epidemic, while the 'non-pharmaceutical' intervention measures utilized in the dynamic Zero-COVID policy could play significant roles in the containment of Omicron. Based on the parameterized model, numerical analysis demonstrates that if one wants to achieve epidemic control by fully utilizing the effect of 'dynamic Zero-COVID' measures, therefore social activities are restricted to the minimum level, and then the economic development may come to a halt. The insight analysis in this work could provide reference for infectious disease prevention and control measures in the future.

Keywords: dynamic modeling; data-driven; Omicron; immune evasion; dynamic Zero-COVID policy

1. Introduction

Beginning from the end of 2019, Coronavirus Disease 2019 (COVID-19) spread over most of the countries and regions in the world, and it developed into Alpha, Delta, Omicron and other variants [1, 2]. The SARS-CoV-2 Omicron variant ('Omicron') is now the dominant strain, and the first confirmed Omicron case in China was discovered among arrival passengers in Tianjin in December 2021. Compared with the Delta variant, the Omicron variant has a faster, more occult transmission and is more resistant to most therapeutic antibody drugs [2–4]. On March 4, 2022, five confirmed cases were reported in Changchun, after which the epidemic was propagated throughout the city. In face of the outbreak, Changchun announced a lockdown of the city on March 11, started to build cabin hospitals and initiated several rounds of escalating non-pharmaceutical intervention measures, such as 'tracking', 'quarantine' and 'city-wide nucleic acid testing', to control the epidemic in the middle of May, with the accumulated confirmed cases as high as 46,533 cases.

Vaccine immunization is one of the most effective measures for prevention and control of the COVID-19 pandemic, and it can be deemed as the cornerstone for changing the global epidemic situation [5, 6]. The continuously emerging variants of COVID-19 have developed immune evasion capability for vaccines designed for the original strain [7–10], and they are able to penetrate the immune barrier formed under the existing vaccine coverage, making it difficult to control the COVID-19 epidemic. D. Planas et al. discovered that, compared with the original strain, the neutralizing activity of vaccines against Omicron decreased by 22 times [9]; Andrews et al. compared the effectiveness of vaccines for Delta and Omicron variants, and found the penetration rate of the Omicron variant in vaccines to be significantly higher than that of the Delta variant [11]. Although vaccines designed for the original COVID-19 strain cannot guarantee long-lasting immune protection, some vaccinated individuals still have immunity against new variant strains [12–14]. Chris Baraniuk demonstrated that, for any individual completing the full vaccination, the risk of infection with the Delta variant could be reduced by 50–60% [15], so it is necessary to develop Omicron specific vaccines, complete full vaccination as soon as possible, and increase the vaccination coverage. Sah et al. studied the epidemic of several states in the USA, and they stressed that if the vaccination coverage of the adult population in every state could reach 74.0%, the number of infected persons could be reduced significantly in USA [16]; Banho et al. further proved that mass vaccination was critical to decreasing cases and deaths to counter variants of COVID-19 [17]. According to the opinion of the Chief Expert for Infectious Diseases and Epidemiology of the Zhejiang Center for Disease Prevention and Control, to realize a quick response to the impact of mutation of the virus on immune efficiency, it is critical to improve the immunization coverage and protection effectiveness of vaccines [18]. As of February 2022, 87% of the population in China has completed the full vaccination [19], but, considering Omicron's immune evasion rate of about 35% for existing vaccines [20], the epidemic outbreak in Changchun still sounded the alarm for us. Therefore, we should evaluate the impact of immune evasion on vaccination and other measures based on actual data, and then adjust the prevention and control measures and implementation intensity accordingly.

In addition to pharmaceutical intervention measures such as 'vaccine immunization', non-pharmaceutical intervention measures are also effective measures that are commonly applied to fight an epidemic. An important variable in the spread of an epidemic is the movement of the population; increased movement provides greater opportunity for virus transmission [21]. Without the effective diagnostic reagent, Wuhan resolutely adopted the 'lockdown' policy, and successfully controlled the

COVID-19 epidemic in several months, a sharp contrast to the condition in most areas of world [22]. Wang et al. concluded in their quantitative evaluation that, if Wuhan postponed the 'lockdown' for seven days, then the confirmed cases in other provinces, municipalities and autonomous regions of China would increase by 3.3–3.9 times [23]. Chinazzi et al. found that the 'lockdown' of Wuhan postponed the overall epidemic process in China for 3–5 days [24]. Measures to restrict social distance have been proven to effectively control the propagation of COVID-19. However, a prolonged lockdown would impede economic development and affect the quality of life and mental health of residents [25–28].

To minimize the of the impact COVID-19 epidemic, China has developed the current overall guidelines for the epidemic prevention and control, i.e., the dynamic zero-COVID policy, in which 'dynamic' refers to 'multi-round' and 'repeated' efforts, and 'Zero-COVID' means 'to eliminate each case identified'. The policy mainly covers three aspects: 1) quickly identifying the infection source through testing and proactive screening; 2) after discovering cases, quickly initiating intervention measures such as multiple rounds of city-wide nucleic acid testing, strict tracking quarantine, control of epidemic spots, constructing cabin hospitals, epidemiological surveys, etc. 3) effectively rescuing and treating infected patients with combined therapy of Chinese and Western medicine [29]. As the 'dynamic Zero-COVID' policy was found to be directly related to the nucleic acid testing rate ('testing rate') in the city, Changchun gradually escalated the control measures after 'lockdown', e.g., issuing four rounds of '5-day Zero-COVID plan', and conducting 'multi-round city-wide nucleic acid testing', so the city-wide testing rate increased gradually in all stages, identifying more patients to be transferred for quarantine and treatment. Before Changchun was locked down, most of the cases were found through voluntary nucleic acid testing, with the accumulated confirmed cases amounting to less than 300 cases, just like only a small part of the iceberg is visible to the eyes after emerging from sea level in the 'iceberg phenomenon'; and subsequently, with the furtherance of the 'dynamic Zero-COVID' measures, confirmed cases increased significantly, indicating that a large number of infected patients were not detected and confirmed in the beginning of the epidemic, just like the majority of the iceberg below the surface is not identified. It was the unrevealed at-risk population that caused the quick propagation of the epidemic. 'Dynamic Zero-COVID' measures are essential for quick identification and quick transfer of the infected; the actual effect relies on large quantities of prevention and control resources, and it is also subject to immune evasion, social distancing, timing of lockdown and other factors. Currently no data-driven studies and analyses on the effect of 'dynamic Zero-COVID' measures have been found for the Omicron epidemic.

In the last two years, the constant mutation of the novel coronavirus has caused many obstructions to the epidemic's prevention and control. Omicron spreads faster than previous variants and is more capable of evading antibodies, increasing the chances of reinfection in the immunized population [2–4, 30]. The transmission of Omicron has a significant impact on the control of the SARS-CoV-2 pandemic. It is necessary to discuss and analyze the control effect of a series of 'pharmaceutical' or 'non-pharmaceutical' intervention measures and response programs under the continuous impact of new variants. In this study, based on the dynamic transmission model of Omicron, actual data of the outbreak in Changchun, estimated infection rate, pre-lockdown community detection rate and other key parameters, the impact of 'immune evasion' of the Omicron variant on vaccine immunization and other measures was evaluated. Additionally,the active role of the 'dynamic Zero-COVID' measure and the impact of relevant factors in this round of epidemic control were quantitatively analyzed, providing the reference for infectious disease prevention and control measures in the future.

2. Data

The data of the study was taken from the official reports of the Changchun Health Commission [31], chiefly including daily added confirmed cases and added asymptomatic cases in Changchun (Figure 1). On March 4, Changchun first reported five confirmed Omicron cases, and after about one week of concealed development, the confirmed cases for the whole city increased significantly on March 11. To prevent outflow of the epidemic and cut off the concealed transmission links in the city, Changchun triggered a 'lockdown' of the city on the afternoon of March 11, closing expressways and the urban public traffic system gradually. On March 12, Changchun started to implement the 'dynamic Zero-COVID' strategy, i.e., the city conducted several rounds of city-wide nucleic acid testing, treated the infected patients, quarantined close contacts, demarcated the 'lockdown zones', 'controlled zones' and 'precautionary zones' according to the actual conditions, and continuously enhanced the intensity in implementing the control measures, until there was reversion of epidemic transmission and zero-COVID cases.

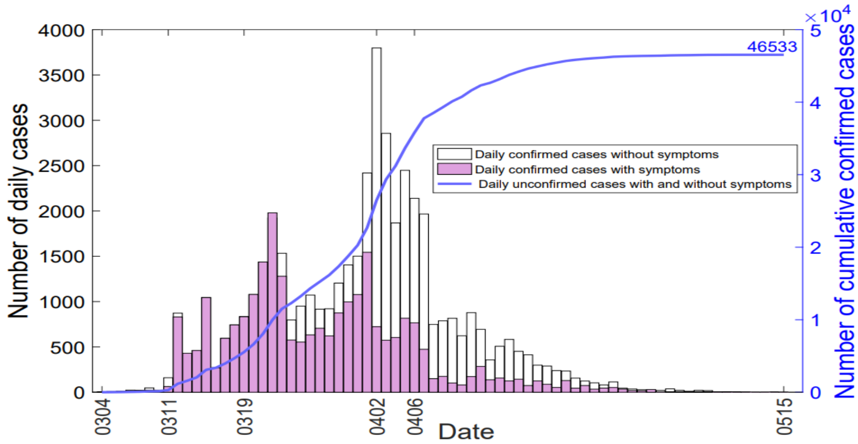

Figure 1. Cases in Changchun on March 4 to May 15, 2022. The data was taken from the official website of the Changchun Health Commission, where the blue solid lines denote the total confirmed cases (inclusive of asymptomatic infected individuals), white bars denote the daily added confirmed cases, and red bars denote the daily added asymptomatic cases.

Since the outbreak of the Omicron epidemic in Changchun, the testing capability had been continuously improved with the arrival of aiding resources from other areas of the country, cabin hospitals had been completed one by one to effectively increase the patient transfer efficiency, and the implementation intensity of the 'dynamic Zero-COVID' policy was increased constantly. The development process of the epidemic can be divided into the following five stages.

Stage I: From March 4 to March 11, 2022. The first confirmed Omicron case was reported in Changchun on March 4, and the epidemic was in the concealed development stage until March 11.

Stage II: From March 12 to March 19, 2022. From March 12, Changchun entered the "lockdown' state: closed expressways, suspended public traffic operation, and conducted city-wide nucleic acid testing, i.e., the beginning stage of 'dynamic Zero-COVID'.

Stage III: From March 20 to April 2. On March 20, Changchun announced a new round of city-wide nucleic acid testing, escalated the city-wide control measures, and implemented "temporary traffic control' and other measures, i.e., the enhancement stage of 'dynamic Zero-COVID'.

Stage IV: From April 3 to April 6, 2022. Changchun conducted city-wide nucleic acid testing again on April 3 and April 5, i.e., the strike stage of 'dynamic Zero-COVID'.

Stage V: From April 7 to May 15, 2022. Changchun started to implement the 'Zero-COVID status at the community level' on April 7, based on city-wide nucleic acid testing and 'one city pairing one district'. Furthermore, there was only one newly added infected case on May 15 and there were no newly added cases for two consecutive weeks thereafter, i.e., the deepening stage of 'dynamic Zero-COVID'.

3. Methods

3.1. Dynamic model

Based on the theory of dynamic compartment modeling for infectious diseases, the transmission characteristics of Omicron and the effect of dynamic Zero-COVID strategies in Changchun, we classify the population into the following 10 compartments: susceptible individuals ($S(t)$), vaccinated individuals ($V(t)$), quarantined individuals vaccinated ($Q_1(t)$), quarantined susceptible individuals ($Q_2(t)$), exposed individuals ($E(t)$), infected individuals with symptoms ($I(t)$), infected individuals without symptoms ($A(t)$), quarantined individuals exposed ($Q_E(t)$), infected individuals treated in the hospital ($H(t)$) and recovered individuals ($R(t)$).

In the formulation of the model, the vaccination and flow of the population during the Omicron epidemic were not considered; the penetration rate of Omicron for existing vaccine protection barrier was assumed to be δ, i.e., apart from susceptible individuals (S), vaccinated individuals (δV) could also be infected with Omicron. Assume that the average number of contacts of each person in the unit time is C, the tracking rate for individuals with close contact with confirmed cases is q, and the probability of having close contact with confirmed cases and infectious individuals is β. Then the number of exposed individuals per day can be calculated by the following equation: $E = \beta(1-q)\delta C\frac{V}{N}(I+A) + \beta(1-q)C\frac{S}{N}(I+A)$. Furthermore, the number of quarantined exposed individuals per day can be calculated by $Q_E = \beta q\delta C\frac{V}{N}(I+A) + \beta\delta C\frac{S}{N}(I+A)$. Also, $(1-\beta)qC\frac{V}{N}(I+A)$ vaccinated individuals (V) per day were quarantined in Compartment Q_1 as they were close contacts, and $(1-\beta)qC\frac{S}{N}(I+A)$ susceptible individuals (S) were quarantined to Compartment Q_2 as they were close contacts, with a quarantine period of $1/\lambda$ days. The quarantined exposed individual (Q_E) was confirmed after $\frac{1}{\alpha_{Q_E}}$ days (slightly shorter than the exposed days) and transferred to Compartment H. In the unit time (per day), the number of asymptomatic and symptomatic infected individuals who were not tracked during the incubation period and became infected after the incubation period is $\sigma\epsilon E$ and $\sigma(1-\epsilon)E$ respectively.

Under the dynamic Zero-COVID policy, Changchun continuously conducts city-wide nucleic acid testing, screening positive cases in the population at the fastest speed. Infected individuals, regardless of whether they show symptoms or not, are immediately isolated or treated upon confirmation. Therefore, we assume that those who are infected do not have transmissibility in the early stages of infection when the nucleic acid test shows a false 'negative', i.e., the exposed E. As for symptomatic infectious individuals (and asymptomatic infectious individuals who are contagious, they are isolated for treatment after being confirmed by nucleic acid testing. The symptomatic case (I) and asymptomatic case (A) not identified and quarantined in the city were confirmed through nucleic acid screening at the speed of αI and αA ,where denotes the average hours of the infected individuals from acquiring Omicron transmissibility to confirmed diagnosis and transfer to a designated hospital for treatment. Then individuals are transferred to Compartment H. In the end, infected individuals with symptoms (I), infected individuals without symptoms (A), and confirmed cases treated in hospital (H) recovered at the speed of $\gamma_I I$, $\gamma_A A$ and $\gamma_H H$ respectively, and were transferred to Compartment R.

Parameter α serves as the city-wide testing rate, under the dynamic Zero-COVID policy where individuals are isolated and treated immediately upon detection and confirmation, it can also be the proportion of infectious individuals ($A(t) + I(t)$) entering designated hospitals for treatment.Thus, α can also be understood as the hospitalization rate. Meanwhile, using α as the transfer rate at which compartments $A(t)$ and $I(t)$ enter $H(t)$, in the sense of mean-field modeling, $1/\alpha$ represents the average time an individual stays in compartments $A(t)$ and $I(t)$ before entering $H(t)$.

The following dynamic model is formulated according to the Figure 2.

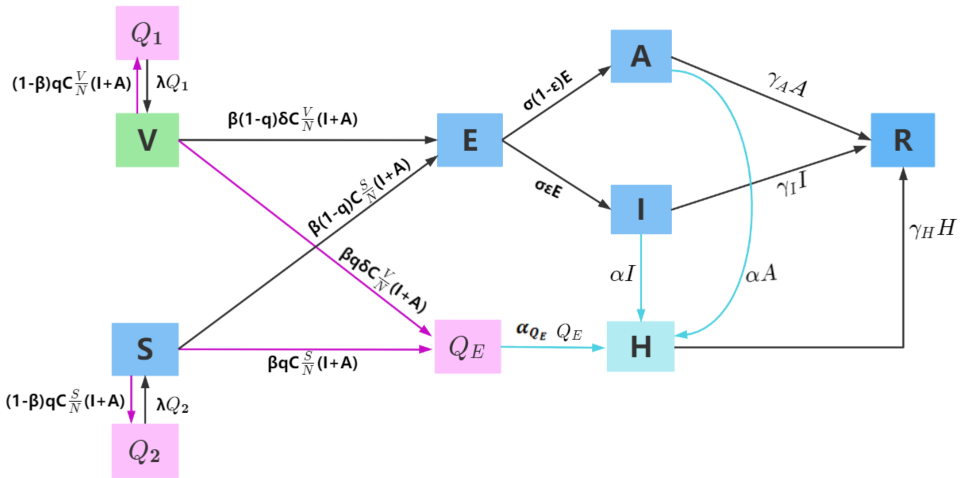

Figure 2. Flow diagram of the transmission of Omicron in Changchun.

$$
\begin{cases}
\dfrac{dV}{dt} = -(1-\beta)qC\dfrac{V}{N}(I+A) - \beta(1-q)\delta C\dfrac{V}{N}(I+A) - \beta q\delta C\dfrac{V}{N} + \lambda Q_1, \\
\dfrac{dS}{dt} = -(1-\beta)qC\dfrac{S}{N}(I+A) - \beta(1-q)C\dfrac{S}{N}(I+A) - \beta qC\dfrac{S}{N} + \lambda Q_2, \\
\dfrac{dQ_1}{dt} = (1-\beta)qC\dfrac{V}{N}(I+A) - \lambda Q_1, \\
\dfrac{dQ_2}{dt} = (1-\beta)qC\dfrac{S}{N}(I+A) - \lambda Q_2, \\
\dfrac{dE}{dt} = \beta(1-q)\delta C\dfrac{V}{N}(I+A) + \beta(1-q)C\dfrac{S}{N}(I+A) - \sigma E, \\
\dfrac{dI}{dt} = \sigma\epsilon E - \alpha I - \gamma_I I, \\
\dfrac{dA}{dt} = \sigma(1-\epsilon)E - \alpha A - \gamma_A A, \\
\dfrac{dQ_E}{dt} = \beta q\delta C\dfrac{V}{N}(I+A) + \beta qC\dfrac{S}{N}(I+A) - \alpha_{Q_E} Q_E, \\
\dfrac{dH}{dt} = \alpha I + \alpha A + \alpha_{Q_E} Q_E - \gamma_H H, \\
\dfrac{dR}{dt} = \gamma_I I + \gamma_A A + \gamma_H H.
\end{cases}
\tag{3.1}
$$

According to the Next-Generation method [32], matrix $\mathcal{F}$ and $\mathcal{V}$ are defined as follows:

$$\mathcal{F} = \begin{bmatrix} 0 & \beta(1-q)\delta C\frac{V}{N} + \beta(1-q)C\frac{S}{N} & \beta(1-q)\delta C\frac{V}{N} + \beta(1-q)C\frac{S}{N} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$\mathcal{V} = \begin{bmatrix} \sigma & 0 & 0 \\ -\sigma\epsilon & \alpha+\gamma_I & 0 \\ -\sigma(1-\epsilon) & 0 & \alpha+\gamma_A \end{bmatrix}.$$

Then,

$$\mathcal{V}^{-1} = \begin{bmatrix} \frac{1}{\sigma} & 0 & 0 \\ \frac{\epsilon}{\alpha+\gamma_I} & \frac{1}{\alpha+\gamma_I} & 0 \\ \frac{1-\epsilon}{\alpha+\gamma_A} & 0 & \frac{1}{\alpha+\gamma_A} \end{bmatrix},$$

$$\mathcal{F}\mathcal{V}^{-1} = \begin{bmatrix} \frac{\epsilon}{\alpha+\gamma_I}\beta(1-q)\frac{C}{N}(\delta V+S) + \frac{1-\epsilon}{\alpha+\gamma_A}\beta(1-q)\frac{C}{N}(\delta V+S) & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}.$$

Therefore, the control reproduction number is

$$R_V = \rho(\mathcal{F}\mathcal{V}^{-1}) = \frac{\epsilon}{\alpha+\gamma_I}\beta(1-q)\frac{C}{N}(\delta V(0)+S(0)) + \frac{1-\epsilon}{\alpha+\gamma_A}\beta(1-q)\frac{C}{N}(\delta V(0)+S(0)). \tag{3.2}$$

3.2. Parameters estimation

The data-driven study on infectious diseases has been accepted by many experts and scholars. It can be used for estimating the infection rate and other unknown key parameters based on the dynamic model formulation with differential equations and the related data for the number of infected cases, deaths, recovered cases, etc. to further predict the trend of disease transmission and analyze the effect of prevention and control measures. In our study, based on the dynamic model (3.1), and the data of confirmed cases in Stages I–IV (March 4 to April 6) published by the Changchun Health Commission, the Omicron infection probability (β) , and the city-wide testing rate in Stage I :

$$\alpha_1 := \alpha \mid_{StageI},$$

and the initial value of exposed individuals $E(0)$ were estimated.

The values of some parameters and initial value of status variables in Model (3.1) are shown in Table 1. According to the bulletin for the 7th national census, the total population of Changchun (N) is about 9,066,906 persons [33]. As of February 26, 2022 , 87% of the population in China have completed full

Table 1. Variables definition, initial value and source.

Symbol	Definition	Initial value	Source
$V(t)$	Vaccinated individuals	$N * \theta = 7,888,208$	[19,33]
$S(t)$	Susceptible individuals	$N * (1-\theta) = 1,178,690$	[19,33]
$Q_1(t)$	Quarantined individuals vaccinated	0	[34]
$Q_2(t)$	Quarantined susceptible individuals	0	[34]
$E(t)$	Exposed individuals	82.1853	Estimated
$I(t)$	Infected individuals with symptoms	5	[34]
$A(t)$	Infected individuals without symptoms	0	[34]
$Q_E(t)$	Quarantined individuals exposed	0	[34]
$H(t)$	Infected individuals treated in hospital	0	[34]
$R(t)$	Recovered individuals	0	[34]

vaccination [19], so we assume $V(0) = 87\% * N = 7,888,208$, and $S(0) = N - V(0) = 1,178,690$. The number of confirmed cases reported by the Changchun Health Commission on March 4 is taken as the initial value of infected individuals with symptoms $I(0)$ [34]. The study of Kuhlmann et al. [20] showed that the penetration rate of Omicron for existing vaccine protection was $\delta = 0.35$. Based on the study of Milne et al. [37], the incubation period of Omicron was assumed as three days ($\frac{1}{\sigma} = 3$) in the study. Referencing relevant studies on social contact [36], the number of contacts before lockdown was assumed to be $C = 14$, and with the escalation of control measures in the stages after lockdown, the number of contacts decreased accordingly (see Table 2). With the gradually enhanced implementation intensity of 'dynamic Zero-COVID' measures, the efficiency of city-wide nucleic acid testing and transfer speed of confirmed cases improved continuously, causing a constant increase in the city-wide testing rate. Thus, the city-wide testing rates in the stages after lockdown, denoted by:

$$\alpha_2 := \alpha\mid_{StageII}, \alpha_3 := \alpha\mid_{StageIII}, \alpha_4 := \alpha\mid_{StageIV}, \alpha_5 := \alpha\mid_{StageV},$$

were assumed as 0.5, 0.55, 0.65 and 0.7 respectively. $1/\alpha_i$ denotes the average time of the infected individuals in Stage i ($i = II, III, IV, V$) from acquiring Omicron transmissibility to confirmed diagnosis and transfer to designated hospital for treatment, i.e., the average number of hours that confirmed infected cases remained in Compartments I and A.

The value of parameter α reflects the efficiency of nucleic acid testing and isolation measures taken during the epidemic in Changchun. A smaller value indicates lower efficiency, meaning a longer average time from when an individual becomes infectious to when they are confirmed and treated in designated hospital. Conversely, a larger value indicates higher efficiency and a shorter average time. An infected individual needs to go through nucleic acid sampling, testing, and confirmation notification before finally entering a designated hospital, a process influenced by various factors such as medical resources and manpower. Changchun started city lockdown and city-wide nucleic acid testing on March 12. In the initial stage after lockdown, limited by medical resources and manpower, not all infected individuals could be diagnosed and treated in time. It took about two days on average from symptom onset to confirmation and isolation. In the second stage, with timely supplementation of medical resources and manpower, the efficiency of nucleic acid testing and isolation treatment continually improved, eventually enabling an infected individual to be tested, confirmed, and begin isolation treatment within about one day.

Table 2. Parameters and description, value and source.

Symbol	Definition	Values for the stages					Source
		Stage I	Stage II	Stage III	Stage IV	Stage V	
		3.5–3.11	3.12–3.19	3.20–4.2	4.3–4.6	4.7–5.15	
N	Total population of Changchun			$9,066,906$			[33]
θ	Immunization rate			0.87			[19]
C	Contact rate	14	6	6	4	4	[35]
q	Tracing rate	0.25	0.25	0.25	0.5	0.75	[10,46–49]
δ	Immune evasion rate			0.35			[20]
$1/\lambda$(day)	Quarantine period			14			[36]
$1/\sigma$(day)	Exposed period			3			[37]
ϵ	Proportion of infected cases with symptoms			0.6			[38]
α	City-wide testing rate	0.2591	-	-	-	-	Estimated
		-	0.5	0.55	0.65	0.7	[39]
α_{Q_E}	Testing rate of quarantine			0.55			[39]
γ_I							
γ_A	Recovery rate			0.1			[40]
γ_H							
β	Infection probability of susceptible by infectious per contact			0.4423			Estimated

In our model, the parameter β represents the probability of infection each time a susceptible person comes into contact with an infectious person. The transmission rate is determined by β multiplied by the number of contacts per unit of time (C) and the proportion of susceptible individuals. The number of contacts per unit of time (C) varies at different stages of the epidemic due to various control measures; we assume that the Omicron virus will not mutate in the short term and its probability of infection each time a susceptible person comes into contact with an infectious person remains unchanged during this round of the epidemic.

Based on the least square method and the actual epidemic data of Stages I–IV, estimations were made for the Omicron infection probability β, the city-wide testing rate in Stage I (before lockdown) $\alpha_1 := \alpha \mid_{StageI}$ and the initial value of infected exposed individuals $E(0)$, and the estimation results were verified with the epidemic data of Stage V. According to the data reported by the Changchun Health Commission, the total number of confirmed cases reported on day i ($i = 1, 2, \cdots, 34$) from March 4 to April 6 was recorded as $\widehat{M(i)}$, accordingly, the total number of confirmed cases on day i ($i = 1, 2, \cdots, 34$) calculated with the numerical solution of model (3.1) was denoted as:

$$M(i) = \sum_{k=1}^{i} \Big[\alpha\Big[I(k) + A(k)\Big] + \alpha_{Q_E} Q_E(k)\Big].$$

Then, solve the following optimization problem:

$$Min(\Gamma(\beta, \alpha_1, E(0))) = \min\Big(\sum_{i=1}^{34} \Big[M(i) - \widehat{M(i)}\Big]^2\Big)$$

subject to model (3.1)

to obtain the least square estimation of parameters, where $\Gamma(\beta, \alpha_1, E(0))$ denotes the error between model output and the actual data.

4. Results

4.1. Parameter estimation and prediction

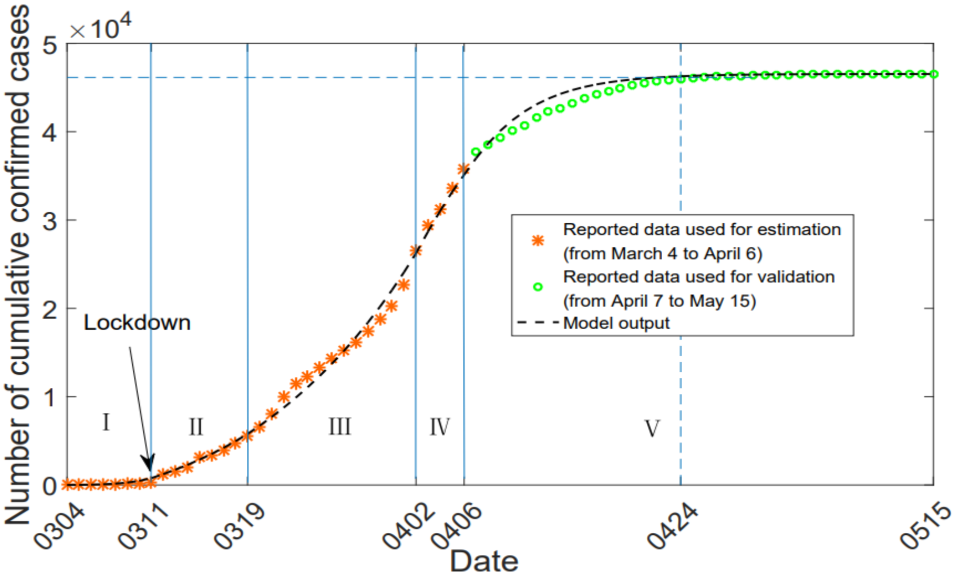

Figure 3. Comparison of model output $M(i)$ with the real daily data. The best fitted curve, i.e., the black dash curve from March 4 to April 6, indicates that our predictions match the reported data of cumulative confirmed cases, i.e., the red stars. The validation of the estimation, i.e., see the black dash curve and the green dots, from April 7 to May 15 also shows that the parameterized model makes a perfect predication. Here, the data of red stars and green dots are the cumulative confirmed cases reported by the CCHC (Changchun Health Commission). The initial values and parameter values are listed in Tables 1 and 2.

Based on the nonlinear least square method and the official reported data from March 4 to April 6, the cumulative case numbers are fitted with the corresponding numbers calculated by the dynamic model, obtaining the estimated parameter values and a well-fitted curve. In Figure 3, all red stars represent the actual data and the black dashed curve represents the model output. Furthermore, the actual data from April 7 to May 15 is used to validate the parameter estimation, and the model prediction curve matches well with the green circles in Figure 3 . These two points indicate that the outputs of the dynamic model match well with the actual data. The results of parameter estimation are shown in Tables 1 and 2. In particular, the cumulative cases from March 4 to April 6 showed the apparent exponential growth trend, but the estimation output after April 6 of the parameterized model reversed the growth trend, quickly returning to stable. Thus, the good fit degree between the prediction results and the actual data (see the black dash curve and the green dots) further verifies the credibility of parameter estimation.

Based on (3.2) and the parameter values, the control reproduction number can be calculated as $R_V = 5.6194$. Sutter Health, [41] calculated the basic control reproduction number for Omicron without epidemic control measures as $R_0 = 9.1$, which is 3–5 times greater than that of the original strain. Before the outbreak, Changchun had implemented vaccination, nucleic acid testing in key populations, mask-wearing and other regular prevention and control measures, so the control reproduction number (R_V) calculated in the study was less than the basic control reproduction number for Omicron (R_0) estimated by Sutter Health.

4.2. Assessment of immune evasion

4.2.1. Immune evasion and vaccination

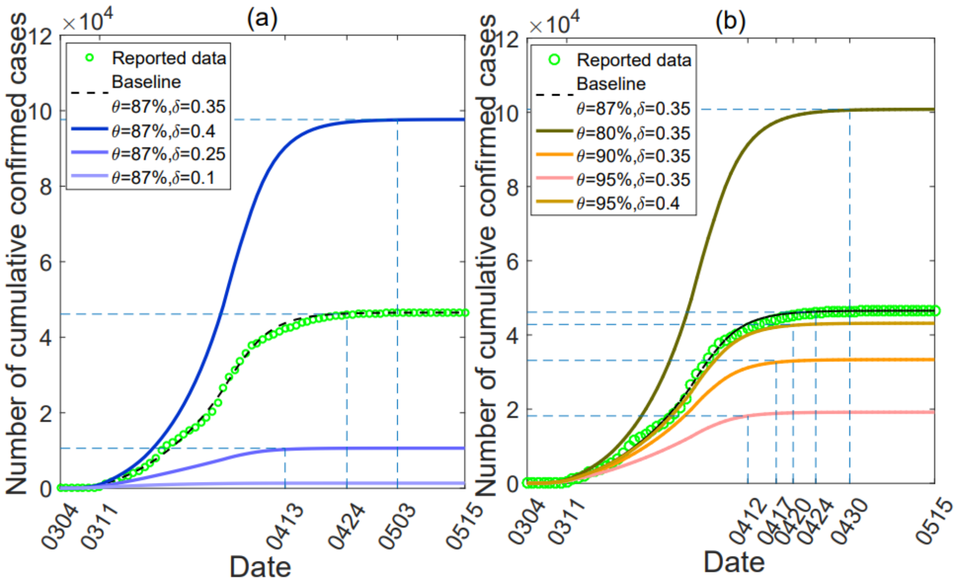

Figure 4. Effect of different immune evasion rates and vaccination coverages. The initial value of vaccinated individuals $V(0) = \theta * N$, and the initial value of susceptible individuals $S(0) = (1-\theta) * N$. (a) Impact of immune evasion rate (δ) on total confirmed cases when vaccination coverage $\theta = 87\%$. As shown in the results, with the existing measures, if δ increased by 0.05, then the total confirmed cases would double, and if δ decreased to 0.1, then the total number of cases could be controlled at a lower level. (b) Impact of vaccination coverage on total confirmed cases. As shown in the results, with the existing measures, when the vaccination coverage increased by 7%, the total number of cases would double, and when the vaccination coverage increased by 8%, the total number of cases would decrease by about 50% . Except for δ and θ , other parameters are the same as those in Figure 3.

Vaccination can serve as a protective barrier to prevent disease transmission. However its effectiveness is reduced by the immune evasion of the COVID-19 variants. In this section, the impact of immune evasion and vaccination on the epidemic transmission and control was analyzed. As shown in the simulation results of Figure 4, with the vaccination coverage before the epidemic outbreak in Changchun, the immune evasion rate showed significant impact on the epidemic development speed, infection scale, ending time, etc. Compared with the actual immune evasion rate of $\delta = 0.35$, if the immune evasion rate equals 0.25, then the total confirmed cases would not exceed 10,000 cases, and the epidemic could be controlled effectively in the middle of April. Similarly, if the immune evasion rate equals 0.1, then the protection barrier of vaccination could be fully utilized, and the final number of infected individuals would be less than 1000 persons. In contrast, if the immune evasion rate equals 0.4, then the period of the epidemic would be further extended, the scale of the epidemic would be increased by about two times, and the total confirmed cases would increase to about 100,000 cases as shown by the dark blue solid line in Figure 4(a).

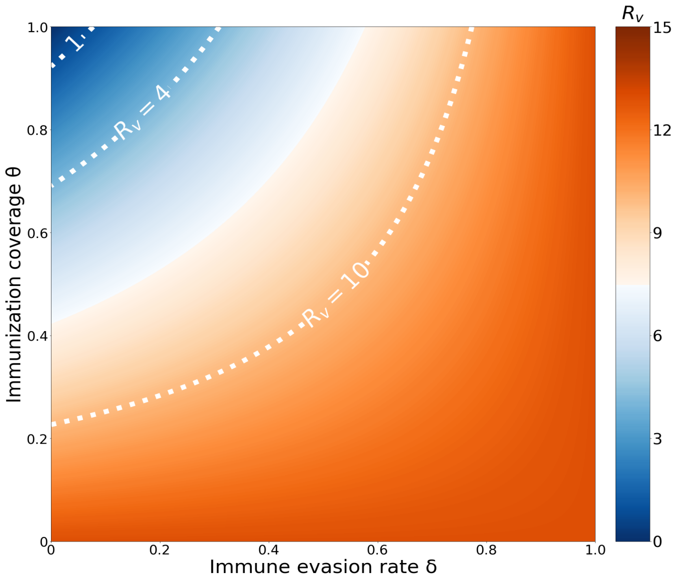

Figure 5. Contour chart of parameters δ and θ for control reproduction number R_v. The side of $R_v < 1$ denotes the controllable area of the disease, suggesting the regular prevention and control measures are far from adequate to prevent and control outbreak of the Omicron epidemic. After lockdown on March 11, immediately adopting the dynamic Zero-COVID strategy was the imperative control approach for Changchun. It demonstrates that only when the immune evasion rate is less than 0.1 and the vaccination coverage is more than 90%, can the Omicron epidemic be controlled. Except for δ, θ and α_1, other parameters are the same as those in Figure 3.

In addition, the impact of different vaccination coverage on the epidemic was considered. As shown in Figure 4(b), when the immune evasion rate of Omicron variant $\delta = 0.35$, and the vaccination coverage was 80% in Changchun (less than the national coverage), the total confirmed cases would exceed 100,000 cases in Changchun; and if the vaccination coverage was 95% and the confirmed cases would be less than 20,000 cases. If the vaccination coverage was 95% and the immune evasion rate was 0.4, the evolution and final scale of the epidemic would be approximate to the actual condition with vaccination coverage of 87% and the immune evasion rate was 0.35 (black dotted lines in Figure 4(b)).

Figure 5 shows the contour chart of the immune evasion rate (δ) and vaccination coverage (θ) for the control reproduction number (R_V), where the side of $R_V < 1$ denotes the controllable parameter area of the disease. As seen in the figure, only when the immune evasion rate is less than 0.1 and the vaccination coverage is more than 90%, can the Omicron epidemic be controlled. For the Omicron variant, regular prevention and control measures are apparently far from adequate to prevent and control the epidemic outbreak.

4.2.2. Immune evasion and city-wide testing before lockdown

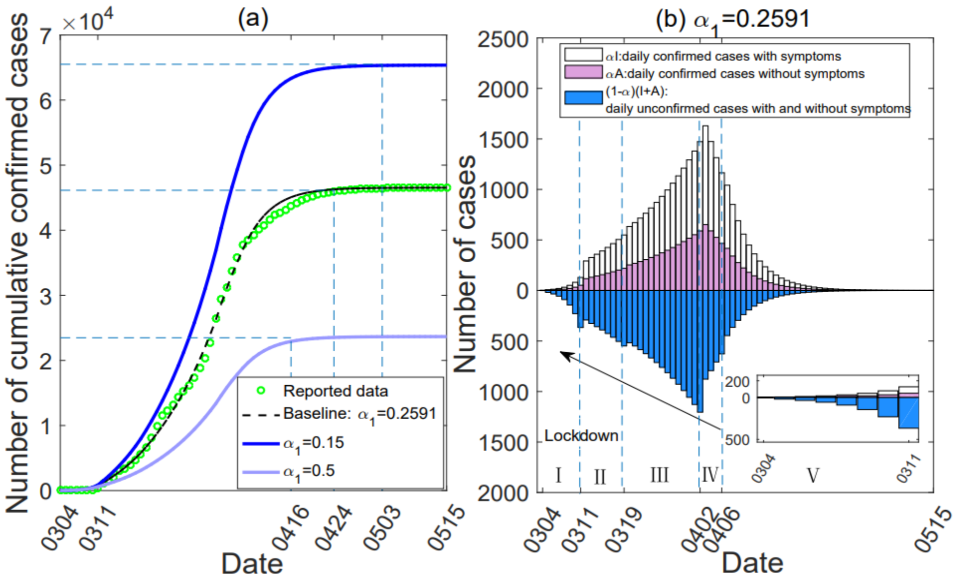

Figure 6. Analysis on impact of city-wide testing rate α_1 in Stage I (March 4-11) on epidemic development. (a) shows the significant impact of the city-wide testing rate at the responsive screening stage on the subsequent epidemic development scale, time of lockdown, etc. If α_1 decreased to 0.15 (i.e., the time from infected individual acquiring transmissibility to confirmed diagnosis and quarantine for treatment was about $1/0.15 = 6.6$ days), the final number of infected cases would be $65,000$ persons, and the end of the epidemic would be extended by about one week. If α_1 decreased to 0.5 (i.e., the time from infected individual acquiring transmissibility to confirmed diagnosis and quarantine for treatment was about $1/0.5 = 2$ days), the final number of infected cases would be about $23,000$ persons (decreased by more than $20,000$ persons as compared with the infected cases), and the epidemic could be ended about one week earlier. (b) Red and white bars above the horizontal line denote Omicron infected individuals confirmed in the city that day (the part of an iceberg above sea level), and blue bars below the horizontal line are Omicron infected individuals not confirmed in the city that day (the part of iceberg below sea level). Except for α_1, other parameters are identical with those in Figure 3.

With an immune evasion rate of 0.35 for Omicron, the percentage of the susceptible population in Changchun surged from 13% of the total population (calculated with 87% full vaccination rate) to 43.45%. The confirmed cases at the early stage of the epidemic were chiefly identified through the voluntary nucleic acid testing of the patients under the regular prevention and control measures, and such cases only covered a very small portion of the actually infected population. Thus, the infected individuals who were not quickly identified became the important factor causing the fast spreading of the epidemic and also the main characteristics of the concealed transmission of Omicron epidemic. Estimation of the city-wide testing rate (α_1) in the early stage of the epidemic could know the overall condition of the iceberg of the epidemic in the early stage. Based on the epidemic data in Stages I-IV, an estimation was made with the least square method to obtain $\alpha_1 = 0.2591$ (Table 2), indicating that only 25.91% of Omicron infected cases were identified and confirmed in the active screening with regular prevention and control measures before the lockdown of Changchun on March 11. Thusm the remaining

74.09% of infected cases were hidden like the portion of an iceberg that sits below sea level, leading to the outbreak of the Omicron epidemic in the end.

In this section, the impact of the city-wide testing rate at the beginning of epidemic (α_1) on the subsequent epidemic development was analyzed. As shown in Figure 6(a), the total number of confirmed cases correlated negatively with α_1 at the beginning of the epidemic. When α_1 decreased from baseline to 0.15, the total confirmed cases were about 1.58 times the baseline (see dark blue solid lines in Figure 6(a)). If the testing rate α_1 increased to 0.5, the total confirmed cases would be about 23,000 cases, dropping about 50% compared with the baseline (light blue solid lines in Figure 6(a)).

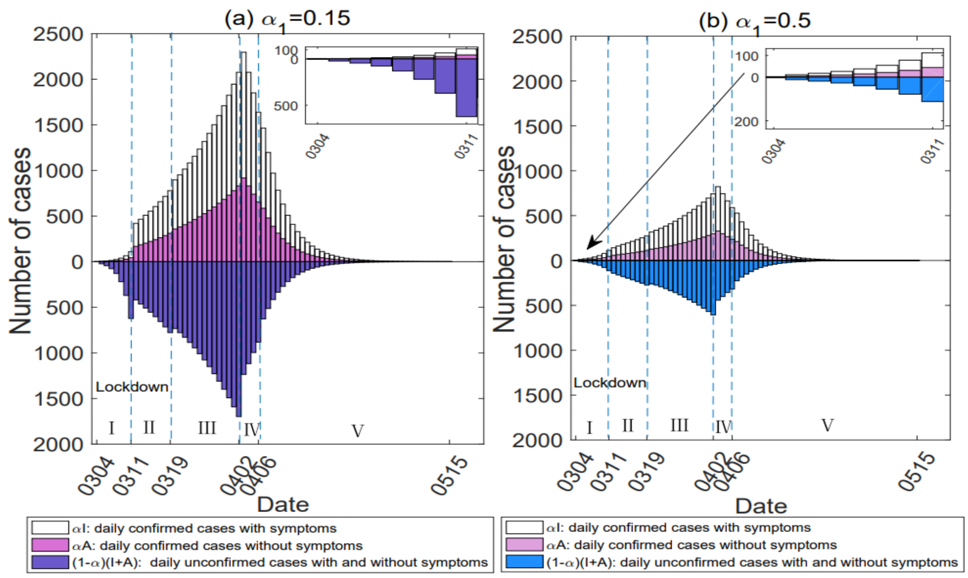

Figure 7. Analysis on the impact of city-wide testing rate α_1 in Stage I (March 4-11) on iceberg phenomenon in infection. Red and white bars above the horizontal line denote Omicron infected individuals confirmed in the community (the visible part of an iceberg), and the blue bars below the horizontal line denote Omicron infected individuals not confirmed in the community (invisible part of an iceberg below sea level). (a) Evolution process of iceberg phenomenon of infection when $\alpha_1 = 0.15$, with the peak value of single-day community infected individuals of about 4000, increasing by about 1/3 compared to when $\alpha_1 = 0.2591$. (b) Evolution process of iceberg phenomenon of infection when $\alpha_1 = 0.5$, with the peak value of single-day community infected individuals of about 1300 persons, decreasing by more than 1/2 compared to when $\alpha_1 = 0.2591$. Except α_1, other parameters in the diagram are the same as those in Figure 3.

As shown in Figure 6(b), with $\alpha_1 = 0.2591$, the newly added cases in Stage I were significantly lower than the infected individuals not confirmed in communities. With the implementation of the 'dynamic Zero-COVID' policy and continuous escalating of control measures, the city-wide testing rate increased to some extent in the subsequent stages the 'iceberg phenomenon' was relieved, and the number of unconfirmed infected cases gradually decreased to zero. Figures 6(b) and 7 depict the evolution of the 'iceberg phenomenon' between the daily number of newly added cases and unconfirmed infected cases in the city, when α_1 was different at the beginning of the epidemic. If $\alpha_1 = 0.15$, a large number of infected cases in Stage I were not timely confirmed, leading to a serious infection in the city, the peak of daily added confirmed cases reaching nearly 2300 cases and the final infected cases axceeding 65,000 cases. If $\alpha_1 = 0.5$, 50% of infected cases in Stage I would be quickly confirmed, significantly relieving the pressure of prevention and control in the subsequent stages; the peak of daily added confirmed cases would be reduced to about 800 cases, less than 50%of the actual condition, and the final number of infected cases would be about 23, 000, effectively reducing the infection scale.

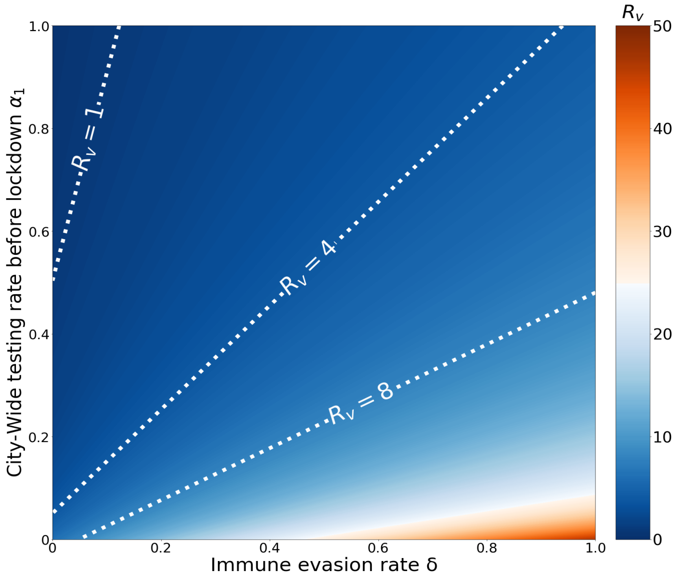

Figure 8. Contour chart of parameters δ and α_1 for the control reproduction number R_v. The side of $R_v < 1$ denotes the disease controllable area, indicating the regular prevention and control measures were far from adequate to prevent the outbreak of the Omicron epidemic. The lockdown on March 11 and subsequent dynamic Zero-COVID strategy were the required control methods for Changchun. Only when the immune evasion rate was less than approximately 0.1, and the community testing rate was higher than 50% at the beginning stage (i.e., before lockdown on March 11, the period from all the infected persons having the infectivity of Omicron to the date of confirmed diagnosis and quarantine is less than 2 days), could the Omicron epidemic could be controlled. Except δ and α_1, other parameters are identical with those in Figure 3.

Figure 8 shows the contour chart of parameters δ and α_1 for control reproduction number (R_V) as shown in the diagram, only when immune evasion rate was approximately less than 0.1 and the city-wide testing rate in the early stage of the epidemic was higher than 50% (i.e., before lockdown on March 11, the time of all the infected cases from acquiring transmissibility of Omicron to confirmed diagnosis and quarantine for treatment was less than 2 days), can the Omicron epidemic be controlled. Apparently, regular prevention and control measures are far from adequate to prevent and control the outbreak of Omicron epidemic. The lockdown on March 11 and the subsequent dynamic Zero-COVID strategy were the imperative control approaches for Changchun.

4.3. Assessment of dynamic Zero-COVID policy

4.3.1. Analysis on intensity of 'dynamic Zero-COVID' measures

The 'dynamic Zero-COVID' policy is the current overall guideline for epidemic control in China. To quickly realize Zero-COVID at city-wide level, Changchun triggered 'lockdown' on March 11, put cabin hospitals into use on March 15, implemented 'temporary traffic control' on March 20, strictly limited social distance, conducted several rounds of nucleic acid testing in the whole city, etc. The 'dynamic Zero-COVID' measures directly increased the city-wide testing rate to ensure infected cases can be identified timely. In the study, the simulation analysis was made for the impact of the city-wide testing rate at Stages II–V of epidemic development.

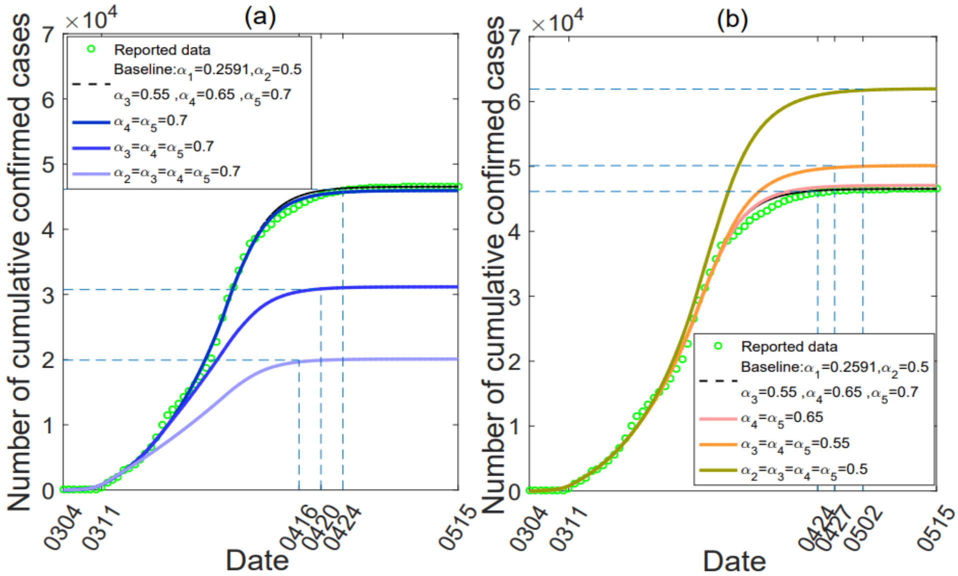

Figure 9. Effect of different dynamic Zero-COVID policy implementation on the development of Omicron infection in Changchun. (a) Impact from early implementation of the city-wide testing rate of Stage V (the highest rate) to Stage IV, III and II. If the testing rate could reach 0.7 after lockdown, the final number of infected cases would be about 20,000 persons and the epidemic could be ended earlier in the middle of April. (b) Impact from failure to increase the city-wide testing rate of the stages. If the city-wide testing rate was 0.5 in all stages, the final infected cases would be more than 60,000 persons and the end of the epidemic could be extended to the middle of May. Except α_1, all the parameters are identical to those in Figure 3.

The parameter $1/\alpha_i$ denotes the the average number of days between acquiring transmissibility and being confirmed as infected for Omicron infected individuals in Stage i. Enhancing the 'dynamic Zero-COVID' measures shortens this time frame, allowing Omicron infected individuals to be quarantined in a timely manner to reduce transmission opportunity. Figure 9(a) shows the comparison of the condition of epidemic development when the city-wide testing rate increased gradually to 0.7, and (b) shows the condition of epidemic development when the city-wide testing rate decreased. As shown in the figure, if the city-wide testing rate was increased to 0.7 from Stage II, then the total confirmed cases would be about 15,000 cases less than the preceding scenario. In contrast, if the city-wide testing rate remained at 0.5 without increase from Stage III, then the total confirmed cases increased significantly, and the period of the epidemic would be extended accordingly. Furthermore, if the city-wide testing rate was increased to 0.7 from Stage II, then the total confirmed cases would be about 20,000 cases and the epidemic would have ended one week earlier. In contrast, if the city-wide testing rate remained at 0.5 from Stage II, then the epidemic scale would be expanded significantly and the period of epidemic would be extended by more than one week. As shown in the comparison, increasing the city-wide testing rate could effectively control the spread of the epidemic.

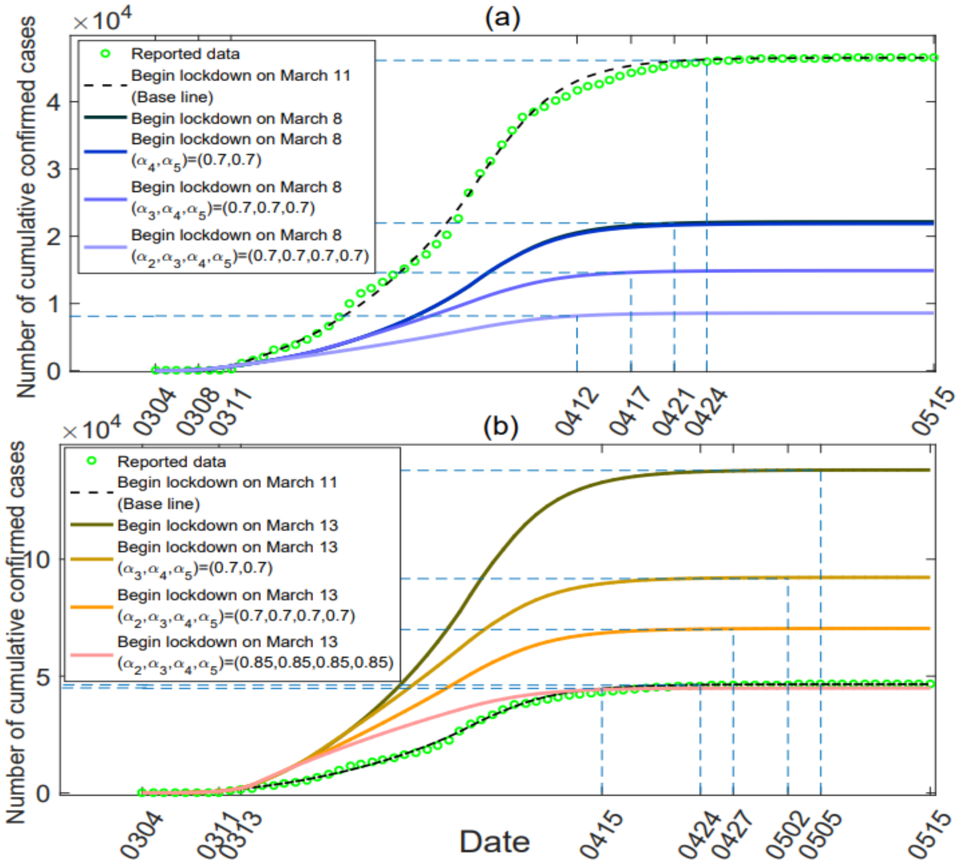

Figure 10. Impact of the timing of 'lockdown' on epidemic development and effect of 'dynamic Zero-COVID' measures. (a) If the initiation of the 'lockdown' was advanced to March 8, with other measures unchanged, the final number of infected persons would be about 20, 200 persons, i.e., less than 50% of the actual infection scale, and the epidemic would end about three days earlier. If the 'dynamic Zero-COVID' measures were enhanced at the same time, i.e., increase the testing rate of Stage IV, III and II to $\alpha_5 = 0.7$ of Stage V, then the epidemic scale would be further reduced and the end of the epidemic would be earlier. (b) If 'lockdown' was postponed to March 13 with other measures unchanged, then the final total infected individuals would be about 138, 000, i.e., nearly three times of the scale of actual infection, and the end of the epidemic would be extended to around May 5. If the enhanced 'dynamic Zero-COVID' measures were initiated more quickly, i.e., increase the testing rate of Stage IV, III and II to $\alpha_5 = 0.7$ of Stage V, then the epidemic scale could be reduced to some extent, but the epidemic could be controlled to the scale equivalent to the actual scale, only when the testing rate in Stage IV, III and II was increased to 0.85.

4.3.2. 'dynamic Zero-COVID' and timing of 'lockdown'

The 'lockdown' policy will cause tremendous impact and involves many aspects, so any city would not readily make the decision to trigger 'lockdown' if it was not under the threat of an outbreak of COVID-19 epidemic. To stop spreading of Omicron, Changchun municipal government announced 'lockdown' of the city on March 11. In this section, the impact of the timing of 'lockdown' on the epidemic development and the effect of ‘dynamic Zero-COVID’ measures were simulated.

As shown in the numerical simulation results in Figure 10(a), if the lockdown was triggered earlier, the epidemic scale could be reduced significantly. For instance, if the time of lockdown was advanced to March 8 with other measures unchanged, the number of infected individuals would be decreased by about $20,000$ persons, and the end of the epidemic could be about three days earlier. Also, if the ‘dynamic Zero-COVID’ measures were enhanced at the same time, i.e., increase the testing rate of Stages IV, III and II to $\alpha_5 = 0.7$ of Stage V, as compared with Figure 9(a) with the same intensity of ‘dynamic Zero-COVID’ measures, the epidemic scale was further reduced by about 50% and the epidemic was ended four days earlier. Alternatively, if the time of lockdown was postponed to March 13, with other measures unchanged, the final total number of infected cases would be $138,000$ persons i.e., nearly three times of the actual scale, and the end of the epidemic would be extended to around May 5. Also, if the enhanced ‘dynamic Zero-COVID’ measures were initiated quickly, i.e., increase the testing rate of Stages IV, III and II to $\alpha_5 = 0.7$ of Stage V, the epidemic scale could be reduced to some extent, but the epidemic could be controlled to the scale equivalent to the actual scale, only when the testing rate in Stages IV, III and II was increased to 0.85.

The process reveals that Changchun triggering ‘lockdown’ on March 11 and adopting ‘dynamic Zero-COVID’ policy were very critical and timely control measures, playing important roles in preventing the outbreak of the epidemic in a larger scope and scale.

5. Discussion and conclusions

The data-driven dynamic study for infectious diseases was conducted for assessing the implementation effect of measures, to help relevant authorities develop reasonable prevention and control plans, and minimize the hazards caused by diseases. In the study, targeted at the Omicron epidemic in Changchun in March to May 2022, the vaccination, implementation of ‘lockdown’,‘temporary traffic control’, ‘city-wide nucleic acid testing’ and other ‘dynamic Zero-COVID’ measures were analyzed, and the dynamic model was built, with the key parameters of the stages adjusted appropriately to reflect the changes of medical resources and continuous escalation of prevention and control measures. Based on the data of accumulated confirmed cases from March 4 to April 6, the Omicron infection rate β, the city-wide testing rate α_1 at the early stage of the epidemic, and the initial value of exposed individuals $E(0)$ were estimated with the least square method, and numerical simulation were performed to assess the impact of the immune evasion, dynamic Zero-COVID and other measures on epidemic development in Changchun.

The vaccination rate and the immune evasion rate decide the scale of the susceptible population, so they have tremendous influence over epidemic prevention and control. According to the analysis in Figure 4, under the premise that the vaccination rate in Changchun city was 87% before the outbreak and the immune escape rate of Omicron was 0.35, the reduction in the number of infections when the vaccination rate increases to 95% is much less than the increase in the number of infections when the vaccination rate decreases to 80%. Also, if the immune evasion rate was 0.4, then the final number of Omicron infected cases in Changchun would double. This resulting figure could be roughly equivalent to the actual number of infected cases only when the vaccination rate was increased to 95%. It is very difficult to further increase the vaccination rate, and with the continuous mutation of viruses, vaccination still plays very important role in reducing the infection scale and mortality. Now, there is a major issue for vaccination in China, i.e., the low vaccination coverage among the elderly population, aged 60 and above. Most old men have underlying diseases, and infection with COVID-19 is prone to severe condition or death of them. Therefore, full vaccination and booster injections are very important to the elderly, particularly the senile group. Reddy et al. [42] studied the immunization of COVID-19 vaccine in South Africa, and the results showed that, compared with those without vaccination, vaccination in 20% of the population could effectively reduce 72–76% of deaths in South Africa, and when the vaccination coverage further reached 40%, the number of deaths could be reduced by 82–85%. Therefore, increasing the vaccination coverage of booster injection for enhancing the vaccine immunization barrier is still the key prevention and control measure. Therefore, after the end of this round of Omicron epidemic, Changchun strengthened the work on third dose booster injections, and is working to reach the target of the booster injection coverage over 90%.

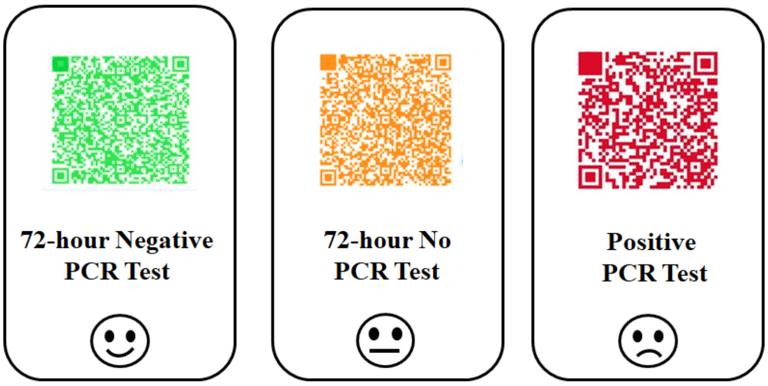

Figure 11. The green code indicates negative nucleic acid test result within 72 hours, the yellow code indicates the time of last negative nucleic acid test result exceeding 72 hours and Red Codes indicates positive nucleic acid test result. Anyone with green code can normally take public traffic means, and access public areas, etc.; anyone with yellow code cannot take public traffic means, or access to public areas requiring green code and any infected individual and the close contacts with red code shall be transferred for quarantine at the first opportunity.

For the outbreak of this round of the Omicron infection, apart from the high immune evasion ability, the short incubation period was also an important factor. The Omicron virus can complete one time of inter-generation transmission in 2–3 days, so small scale epidemic propagation has actually been caused, before a large number of the infected cases were identified with regular prevention and control measures. In the study, based on the dynamic model and epidemic data, it was estimated that only 25.91% of the infected individuals were detected and confirmed with regular prevention and control measures before lockdown of Changchun, and the concealed transmission caused from the remaining 74.09% infected individuals in communities was the "source' leading to the large scale and quick increase of confirmed cases after March 11. The epidemic control process of 'dynamic Zero-COVID' is to identify and quarantine infected cases in the community as soon as possible, reducing this hidden population as soon as possible to zero. Therefore, ensuring the comprehensive and efficient city-wide nucleic acid testing is critical to control the epidemic. After controlling the epidemic with the above measures, Changchun quickly resumed social operation while maintaining the high coverage of nucleic acid testing to effectively control the epidemic in the city.

After lockdown, Changchun immediately closed expressways, suspended operation of public traffic,

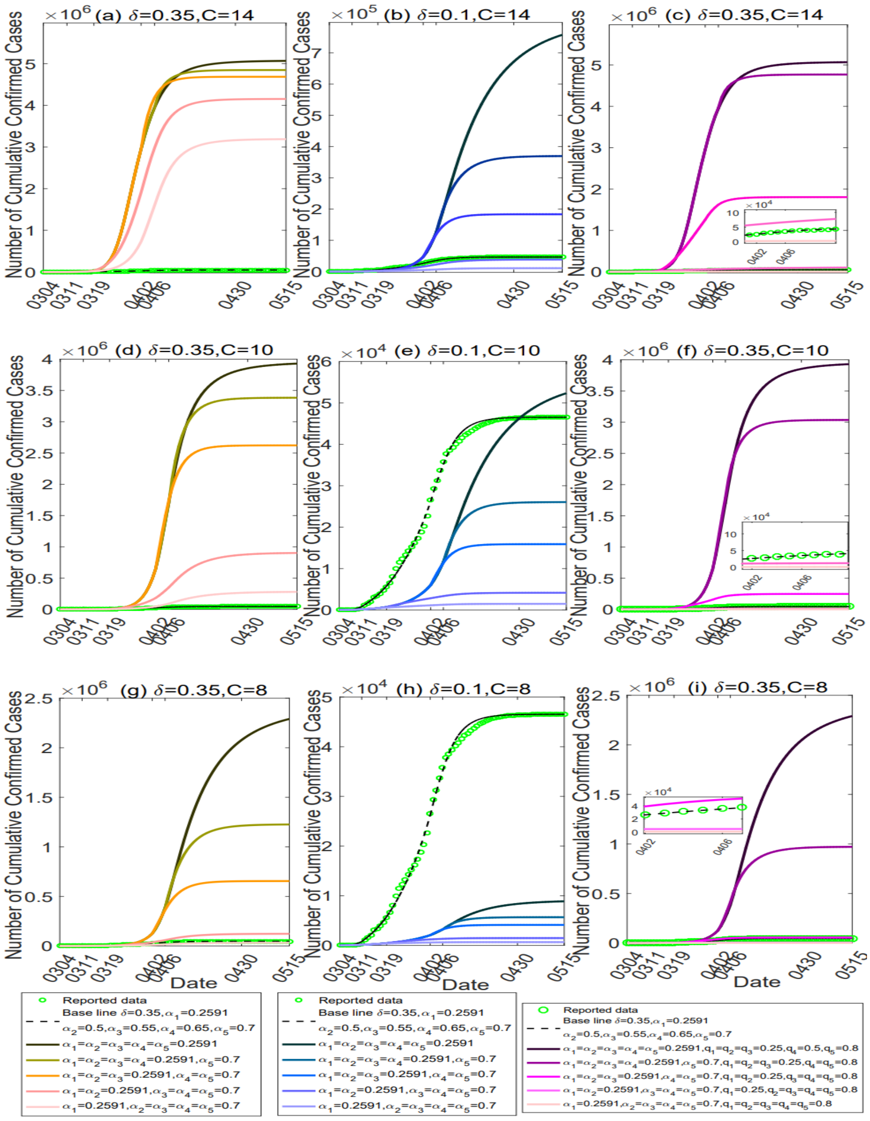

Figure 12. Impact of social distance, immune evasion and 'dynamic Zero-COVID' policy on the spread of the Omicron epidemic. The green circles denote the reported data, and the black dotted line denotes the baseline of Figure 3. Figure (a,d,g) show the impact of different intensities of 'dynamic Zero-COVID' policy on total confirmed cases, when $\delta = 0.35$ and $C = 14, 10, 8$. Figure (b,e,h) show the impact of different intensities of the 'dynamic Zero-COVID' measures on confirmed cases, when $\delta = 0.1$ and $C = 14, 10, 8$. Figure (c,f,i) show the impact of different intensities of 'dynamic Zero-COVID' measures and different tracking quarantine rates q on total confirmed cases, when $\delta = 0.35$ and $C = 14, 10, 8$. Unless otherwise specified in the diagram, the value of other parameters and initial values are the same as those in Figure 3.

revoked access to public areas and took other measures, to effectively limit social distance, and provide opportunities for controlling the epidemic through 'dynamic Zero-COVID'. However, 'lockdown' measures also dragged economic development and social activities to a standstill. Whether it is possible to achieve the epidemic control by fully utilizing the effect of 'dynamic Zero-COVID' measures while maintaining necessary economic and social activities is an issue worthy of analysis and exploration. Therefore, based on Model (3.1) and parameter values, the numerical simulation was made for the number of contacts (C), immune evasion rate (δ), tracking rate (q) other parameters and the control effect of the 'dynamic Zero-COVID' measures. As shown in Figure 12(a), if no limitation was imposed on social distance (i.e., $C = 14$ for all stages), there were sufficient medical resources to ensure full implementation of 'dynamic Zero-COVID' measures multiple rounds of city-wide nucleic acid testing were initiated and timely transfer of all confirmed infected individuals and their close contacts was completed, then the final infection scale would be 5 million infected cases. Furthermore, even if the strictest 'dynamic Zero-COVID' measures (i.e., $\alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0.7$) were taken from March 11, more than 3 million persons would be infected. As seen in Figure 12(d),(g), with further limitation and enhancement of social distance and 'dynamic Zero-COVID' measures respectively, the final infection scale decreased continuously, and when $C = 8$ and the strictest 'dynamic Zero-COVID' measures (i.e., $\alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0.7$) were simultaneously implemented, the final infection scale was similar to the actual scale. As shown in the results in Figure 12(b),(e),(h), if the protection effectiveness of the original strain vaccine against Omicron was maintained at 90%, appropriate social distance limitations could achieve the significant control effect. According to the results in Figure 12(c),(f),(i), the strictest tracking quarantine measures plus social distance limitation and 'dynamic Zero-COVID' measures, though decreasing the infection scale to some extent, could more significantly improve the control effect of vaccine protection compared to the results in Figure 12(b),(e),(h).

The simulation results in Figure 12(g) demonstrate the hope of controlling the Omicron epidemic with limited social distance measures. However, we must be aware of two issues: a clustered outbreak caused from any handful of social activities could drive the epidemic out of control and ensuring the effective implementation of dynamic zero-COVID procedures is challenging while also limiting social distance. In fact, apart from the policies and measures taken by governments, the conscious acts of each citizen under the relatively relaxed prevention and control measures is also an important and critical factor, e.g., consciously avoiding unnecessary outgoing trips, avoiding gatherings with several persons, keeping proper distance when meeting any person, taking proper personal protection measures, etc., which will have profound influence over epidemic prevention and control.

Handling the of pandemic is not merely a medical issue. With the continuous increase in transmissibility and immune evasion ability of new variants of COVID-19 , non-pharmaceutical intervention measures are required to play the active role in addition to vaccines and other drug intervention measures. Once any infection link is identified in the community, multiple rounds of city-wide nucleic acid testing, tracking quarantine and other measures are the key actions for achieving 'Zero-COVID at the community level' as soon as possible. Therefore, if one wants to achieve the epidemic control by fully utilizing the effect of 'dynamic Zero-COVID' measures, all social activities would be restricted to the minimum level and economic development may come to a halt.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare there is no conflict of interest.

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