SIR Model Adjustment for Covid Spread in China

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Abstract. One of the ways to reduce the harm caused by COVID-19 pandemic is developing policies that balance the health and economy of society. These policies rely on large amount epidemic data. Traditional epidemiological SIR models become the basis for COVID-19 models to replicate and predict the epidemic's trend. This study seeks to find out which model is more suitable for countries under strict control policies. Through the collection and analysis of information on the epidemic in China, this study concluded that there are two pieces of data are suitable for this study. In this study, the two parts of data are calculated and combined with other studies to obtain the parameter values for different models. The SIR and SEIR models in this study yielded interesting results. Simulations of the SIR model under mass lockdown policies produced reliable data forecasts for infection days. The SEIR model has a relatively accurate prediction of the trend of the proportion of infections population. However, other models based on COVID-19 characteristics do not produce as much information as compared to the above two models.

Keywords: SIR model; Covid-19; quarantine.

1. Introduction

A virus that infects quickly and spreads easily pose a huge challenge to healthcare. COVID-19 is one such virus that causes health problems. COVID-19 is a description of the disease caused by severe acute respiratory syndrome coronavirus [1]. First officially confirmed patient recorded in 2019 [2]. The transmission of Covid-19 is mainly through direct or indirect contact with an infected person. The infection routes involve contact with saliva and other secretions left behind by an infected person or exposure to respiratory droplets when communicating with an infected person [1]. At the same time, society faces problems such as insufficient testing resources, failure to identify asymptomatic cases, and lack of vaccines or specific antiviral treatments [1]. The diversity of transmission routes of COVID-19 combined with insufficient resources has led to the outbreak and global spread of the epidemic.

The symptoms of Covid-19 were identified though data collected from a large number of patients. The virus infects the respiratory and central nervous systems causing a range of symptoms [2]. Symptoms usually appear much like pneumonia with fever and cough. However, unlike the common cold, individuals infected with COVID-19 often had lingering symptoms and were no longer able to return to the baseline of pre-infection health [3]. The virus can even cause death among people with certain long-term illnesses [4]. Health authorities encourage people to take protective measures to minimize infection. Despite various efforts to stop the virus, such as social distancing, wearing masks, and sanitizing hands, the spread of COVID-19 continues to increase. Some countries have had to adopt quarantine policies to reduce the risk of infection. Quarantine and a nation's overall health and financial wellness are closely related. [5]. Quarantine can minimize the spread of the COVID-19 virus. But it also limits the potential of people to consume in the market which can lead to economic collapse. Some countries have tried to borrow large amounts of debt to survive the crisis. However, this has led to problems with domestic foreign exchange funds [6]. A weak economy and strict regulations increase the chance of developing certain mental health issues [7].

The social problems listed above require each country's government to make quick decisions to stabilize society. However, there was not enough information available in the early phases of the epidemic to demonstrate the viability of various policies. In order to solve the problem of insufficient data, some researchers use the SIR model in epidemiology for analysis. The SIR model in epidemiology is a simple model created from the number of susceptible individuals, the number of infected individuals, and the number of recovered individuals. There are many variables that need to be considered in these models to fit them into the framework of COVID-19. The number of outbreaks, population size, and density can affect the model [4]. In addition, more factors should be considered to make the model perfect to predict the short-term outcome of COVID-19.

In the early stage of COVID-19, many studies improved the SIR Model according to the characteristics of COVID-19. An improved model could analyze and predict the impact of some variables in the epidemic. However, these models require a lot of research time and can cause delays in policy formulation. And there are inevitably differences between the predicted data of these models and the real data. After three years of the epidemic, more comprehensive data was collected so that the accuracy of these early models could be tested. This study focuses on the discrepancy between the data predicted by the early model and the real data under the strict epidemic prevention policy. Especially simple models, because they take less time to produce a rough forecast, which is more effective and faster data for governments that need to make policy decisions. Also, this study includes ideas of some variables that can be improved or ignored in these models under lockdown policy.

2. Methods

2.1. Data Collection

This study used Worldometer as a database, which included official COVID-19 data such as daily new cases, daily recoveries, and deaths toll for most country. The database also includes the information from National Health Commission of the People's Republic of China. For nearly three years, China has followed the "Zero Coronavirus" plan, thereby safeguarding the populace from the COVID-19 [8]. By August 2022, 88.6% of Chinese people had completed the first dose of the vaccine, and 72.4% of Chinese people had received the booster [8]. At the same time, large-scale isolation measures have been implemented, and a large number of investigations have been carried out on the affected areas. This enables Chinese data to document the entire epidemic scenario more thoroughly. Chinese epidemic prevention policy is consistent with the strict control of COVID-19 required in this study. Therefore, this data can be used to test the impact of different models on the prediction of preventive measures.

2.2. Basic SIR Model

The SIR model is based on a constant total population of three separate segments. The population of susceptible individuals is denoted by s, the infected population is denoted by i, and the recovered population is denoted by r. All three parts can be represented by an equation with respect to time. The SIR model is also based on other assumptions: One, when people are infected and recover, they will be immune to the virus. This allows them to be permanently classified into recovery group. Two, the number of contacts between susceptible and infected people affects how quickly the disease spreads.

$$S(t) = -\beta si \tag{1}$$

$$I(t) = \beta si - vi \tag{2}$$

$$R(t) = vi \tag{3}$$

Both v and β are positive parameters. The start condition of an outbreak depends on the rate of change of initial $I(t)$. If it is negative, then no outbreak will occur. If it is positive, then an outbreak will occur.

This model simplifies many features of Covid-19. Infected persons are divided into symptomatic and asymptomatic [3]. As the virus spreads and recovers, different groups behave differently. Asymptomatic infected people will come into contact with more people, increasing the infection rate. The Covid-19 virus can also kill those who are infected. In addition, the rapid mutation of the virus also allows people who have recovered to be infected again [3].

2.3. Other Models

This research adds new classifications or new routes to cover the known characteristics of covid on the basic SIR model. Secondary infection can be reflected by the recovered population entering the susceptible population after a period of time. Latency features can be expressed by adding exposed groups which have different recovered rate and transmission rate. Mortality can be represented by adding the diseased group. The fundamental models used in this study are displayed in Table 1.

Table 1. Streaming explanations for each category in different models

Model	Classification and Process of Group
SIR	Susceptible → Infected →Recovered
SIRD	Susceptible → Infected → Recovered or Diseased
SIRS	Susceptible → Infected → Recovered → Susceptible
SEIR	Susceptible → Exposed → Infected → Recovered

3. Results and Discussion

3.1. Chinese Covid-19 Data

Figure 1 shows the daily number of infections case in China starting from January 21, 2020. The common SIR Model can only simulate one waveform of daily infection rate [9]. In each wave of infection, the number of infections begins to increase significantly. A wave ends when the growth reaches a maximum and then gradually drops to around zero. In Figure 1, the daily new cases in China are divided into three waves. The first wave is from January 22, 2020, to March 28, 2020. The second wave is from March 11, 2022, to May 15, 2022. However, Chinese epidemic prevention has changed during the third wave which is no longer need for extensive testing and quarantine on December 7, 2022[10]. And Chinese official data has not been updated since January 9, 23. Therefore the data from the third wave cannot be used. Although the two waves of data do not completely present a convex shape, the general pattern is eligible for this study. On average, each wave lasted 67 days.

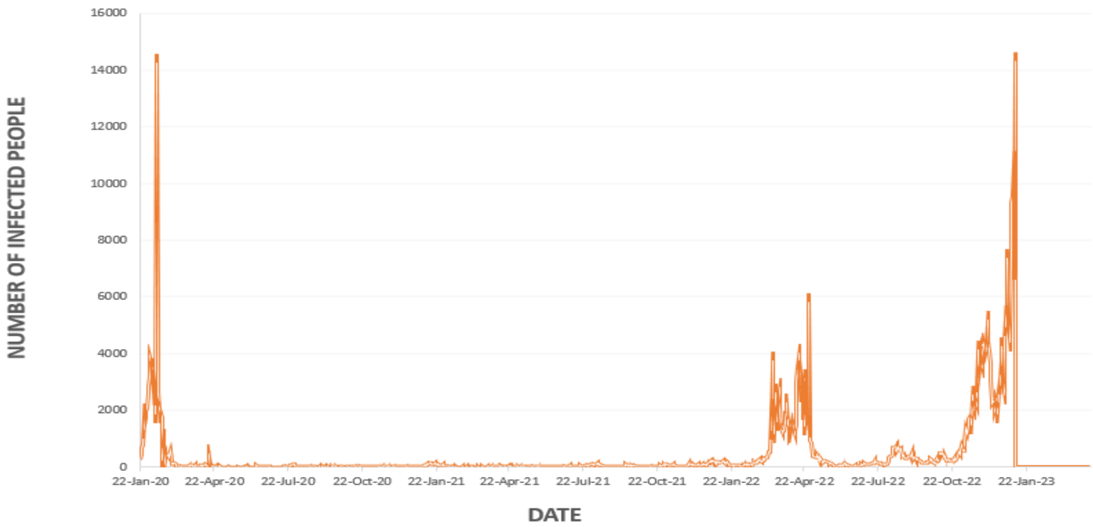

Fig. 1 Daily case in China (the data collected from Worldometer)

3.2. Parameter Value and Simulation

3.2.1. SIR model

Each country has a different transmission rate and recovery rate for covid. The infection rate used in this study is derived from calculating the average of the first two days of the two waves by using formula (4). SIR considers infection rates after contact between susceptible and infected individuals is 1.2×10^{-9}.

$$\frac{S(n+1)-S(n)}{S*I} \tag{4}$$

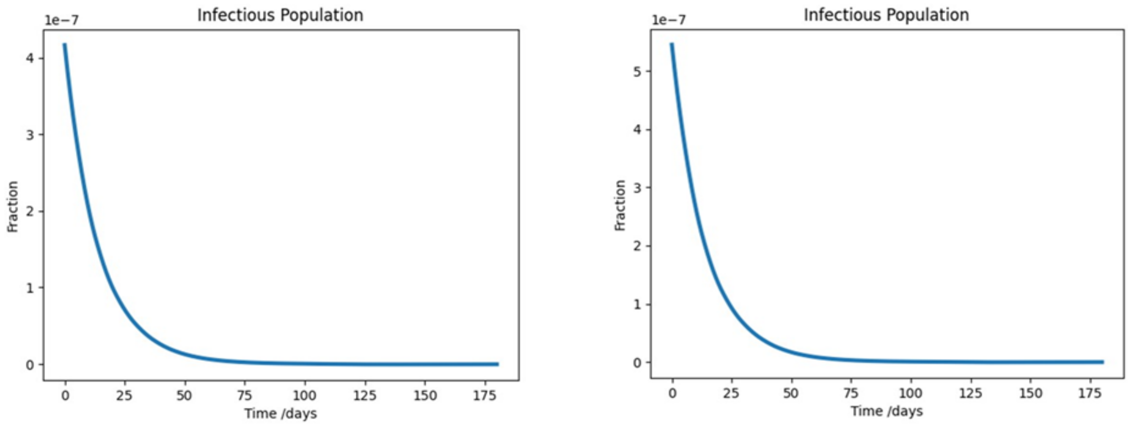

Fig. 2 SIR model for the first wave and second wave

Figure 2 shows the graphs of the number of infected people and time according to different initial values under the SIR model. Both graphs show that at about 65 days all infected persons have recovered, and the number of infected people has a decreasing trend.

3.2.2 SEIR model

People do not develop symptoms or be tested for infection after being exposed to someone with COVID-19. The period from exposure to infection is called the incubation period. There is no relative reflection in the official data because it is impossible to identify individuals throughout the incubation stage. Therefore, this study uses data obtained from other studies to fit the SEIR model in China. The obtained transition rate from exposed to infected In SEIR is 0.142. [11]. The Rate of transmission from suspected to exposed in SEIR is 0.00414 [12].

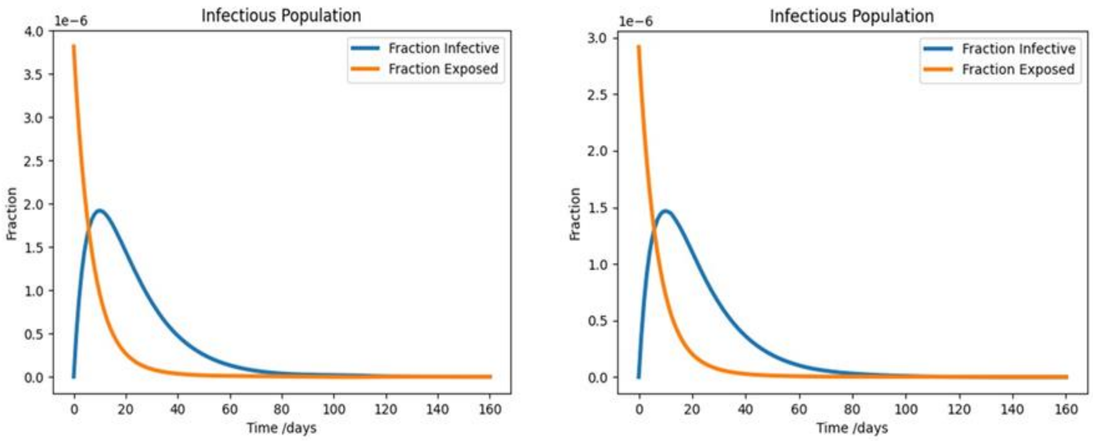

Fig. 3 SEIR model for the first wave and second wave

Figure 3 shows the graphs of the number of infected people and exposed people verse time according to different initial values under the SEIR model. The total number of people exposed in Figure 3 shows a decreasing trend. The total number of infections has slowly increased from zero at the beginning. The total number of exposed people reached the highest value on the 15th day, and then showed a decreasing trend.

3.2.3 Other models

In the SIRD model, based on the total number of COVID-19 deaths in China divided by the number of people infected, the chance of dying among infected people is 0.01. In the SIRS model, the missing information is the probability of reinfection among recovered people. Earlier research showed antibodies in the body can last for more than a year after recovering from COVID-19[13]. The study set the probability of relapse in recovered patients at 0.002. Other parameters remain the same as in the SIR model.

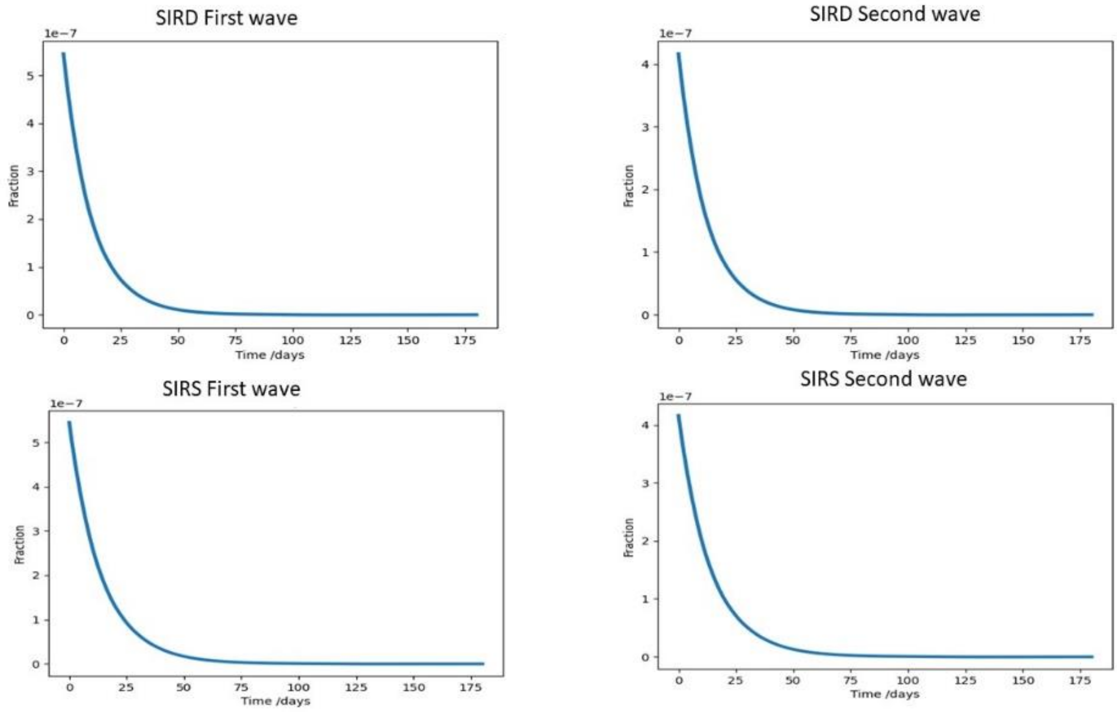

Fig. 4 The first wave and second wave for SIRD model and SIRS model

Figure 4 shows the simulation of infection population under SIRD and SIRS model. The images obtained by these models are similar to the images of the SIR model.

4. Conclusion

The parameters of different pathological models were obtained based on epidemiological data recorded in China and some other studies. All the simple models are run in Python to get the graph of the total number of infections and the infection time for two waves. Through the analysis of the simulated image, the study found that the period of each wave under the SIR model is consistent with the collected data. Although the period in the SEIR model is longer, the graphical trend of the number and time of infections in the SEIR model is more consistent with the real data. In addition to these two models, the trend of the remaining models is similar to the SIR Model, which may be because the fatality and probability of losing antibodies S are underrepresented compared with other parameters. Therefore, in the early stage of the epidemic, if a country is under a large-scale blockade policy, a basic SIR model can be used to estimate the duration of one wave of COVID-19. The values required by this model are easy to calculate. The predictions can provide data support for future epidemic intervention decisions. In addition, it is worth analyzing which pathological models better match collected data under different policy formulations. The results could be used in the future to better respond to the virus that shares similar characteristics with COVID-19.

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