The effect of control measures on COVID-19 transmission in Italy: Comparison with Guangdong province in China

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Abstract

Background
COVID-19 is spreading in many countries around the world. Italy is the hardest hit in Europe and its number of new infections is still increasing. This study aims to evaluate the reason for the rapidly growing epidemic in Italy.

Methods
We compared Italy’s data of outbreak and control measures with the province of Guangdong in China. Then, a modified SEIR model was applied to estimate the basic reproduction number. Finally, we utilized a time-dependent dynamic model to study the future disease dynamics in Italy.

Results
The comparison of specific measures implemented in the two places and the time when the measures were initiated shows that the prevention and control actions in Italy were not sufficiently timely and effective. Using a modified SEIR model, we estimated parameter values based on available cumulative data and calculate the basic reproduction number to be 4.32 before the national lockdown in Italy. Numerical simulations revealed that under a scenario in which very strict interventions are taken when the minimum contact rate is 1 with the exponential decreasing rate is 0.5 and the fast diagnosis rate is 0.5 with the exponential increasing rate is 0.5 (i.e. the test result will be available in two days). In this scenario, Italy will reach the peak (i.e. 23900) after 43 days.

Conclusion
This study suggests that Italy is currently in a very serious epidemic status since control measures such as blockade of schools, isolation, medical supports and media coverage are not sufficiently timely and effective.

Trial registration
Not applicable

Keywords: COVID-19; Cumulative cases; Control measures; Model prediction

Background
Six types of coronavirus have been found to be capable of causing human infections [1]. Four of them are not highly pathogenic, typically causing cold symptoms in immunocompetent individuals, while the other two types, the Severe Acute Respiratory Syndrome...
(SARS) and the Middle East Respiratory Syndrome (MERS), can result in severe respiratory illness and fatalities [2, 3, 4]. In late 2019, a novel coronavirus COVID-19, which turns out to be more infectious and can survive higher temperature than SARS [5], has been identified as the pathogen of an ongoing pandemic. This virus has spread to many countries in the world [6, 7, 8, 9]. By March 13, 2020, more than 31614 confirmed cases with 1210 deaths due to COVID-19 had been reported in Europe. Italy is on the top of the list with more than 15385 confirmed cases and 1016 deaths, which account for 48% of reported cases and 83% of deaths in Europe. It has become a very serious public health crisis in Italy and calls for urgent national interventions. Some indicators that can determine the potential and severity of an outbreak, such as the basic reproduction number and the outbreak peak time, remain unclear in Italy. How to find the most suitable and practical interventions, travel restrictions, media coverage and medical resources for the maximal suppression of the outbreak with the minimal destruction of social-economic activities demands further investigation.

Control measures have been implemented in Italy aiming to contain the outbreak. On February 22, 2020, the Italian Council of Ministers announced a new decree to mitigate the epidemic, including the quarantine of more than 50 thousand inhabitants in 11 northern cities. On March 1, Italy issued a new order on epidemic prevention, which divided Italy into red, yellow, and safe zones. The red zone has 11 isolated towns. Social and sport activities were suspended in the yellow zone. Control tactics and disinfection of public transportation were required in a safe zone. On March 8, Italy further announced that 14 regions such as Lombardy and Modena were included in the blockade region to prevent anyone from entering or leaving the district. On the next day, Italy extended the blockade of Lombardy to the whole country since March 10. How these control strategies can mitigate COVID-19 propagation in Italy is still unknown.

There are many questions about COVID-19 transmission despite interventions in Italy. How many future infections will be generated by each infected individual per day? How long does it take from exposure to symptoms onset? How many people will become infected in total? When will the infection peak arrive and how high is the peak? How many more hospital beds are needed? Will media coverage help control the epidemic? Will the current public health measures be enough to bring COVID-19 under control? When and how should the government implement strategies to achieve the best prevention and control of the epidemic? Mathematical modeling, combined with prevalence data, might provide answers to some of these questions.

In the course of dealing with the worldwide outbreak crisis, mathematical models have played an important role in providing policymakers with timely and crucial epidemiological information. Many models have been developed, for instance, using the transmission model of SARS [10, 11] to investigate the spread of SARS, the molecular SARS model to understand its molecular structure for biochemical function and drug design [12], and animal models of MERS to study how disease passes from animals to humans [13, 14]. The media impact models illustrate how social media influences the propagation of SARS [15]. Mathematical models have also been developed to study the transmission of COVID-19 in response to this current crisis [16, 17, 18, 19]. For example, He et al. have developed a discrete-time stochastic epidemic model with binomial distributions to study the transmission of COVID-19 [20]. Tang et al. used a deterministic compartmental model to investigate the COVID-19 epidemic in mainland China, the Guangdong province of China, and South
Korea [21, 22]. The control measures and the timings of initiation in China might provide some suggestions to other countries [23].

In this paper, we will start with a review of the current data of global and Europe epidemics. We will compare the prevention strategies used in Guangdong province and that in Italy. We will use a deterministic compartmental SEIR model in combination with the latest data from Italy to quantify the effectiveness of these interventions. We will also discuss the practical implications such as various measures used in Italy and what movement should be taken next to better control the COVID-19 outbreak in Italy.

Methods

Data

We obtained data of confirmed COVID-19 cases that were reported in Guangdong province, Italy and other places in the world from the Health Commission of Guangdong Province, the Ministry of Health of Italy, and the World Health Organization [24, 25, 26, 27]. The data include infected cases in the world and Europe since January 26 to March 12, 2020, the cumulative confirmed cases, newly reported cases, death cases, and recovered cases in Italy from January 30 to March 13, 2020 and in Guangdong from January 19 to February 26, 2020. The number of cumulative confirmed cases in Italy was 2 between January 30 and February 5, 2020, and was 3 from February 5 to February 19, 2020. The numbers of cumulative death and recovered cases were 0 from January 30 to February 19, 2020. We exclude the data in these periods and will focus on the Italian data between February 20 and March 13. By analysis of this dataset using a mathematical model, we will compare the prevention and control measures used in Italy and Guangdong.

Global epidemics

Novel coronavirus pneumonia has spread in 114 countries by March 12, accounting for 58.5% of the 195 sovereign states in the world. This means that more than half of the world’s nations are infected. Among them, 49 countries in Europe have been infected, accounting for 98% of the total number of European countries. Only Montenegro in Europe has no confirmed cases.

The global spread of the epidemic has gone through two stages, as shown in Figure 1. In the first stage, COVID-19 spread to 22 countries around the world before the end of January. In this stage, there was a huge deficiency of cognition about this new coronavirus. In early February, under severe blockade of a few cities including Wuhan in China and strict quarantine interventions carried out by other provinces, the epidemic did not spread swiftly to more countries and only increased by seven countries in more than 20 days. Nevertheless, in the second phase, it took only 19 days for the number of infected countries to ascend rapidly from 29 on February 22 to 114 at present. The discrepancy between these two stages is due to the interventions implemented by China and other countries. We select Italy and Guangdong Province of China for data comparison to illustrate the significance of prevention measures to contain the COVID-19 outbreak.

Timing of control measures

In Figure 2, we select February 20 as the first day when there were 4 cumulative confirmed cases in Italy, and January 19 as the first day when Guangdong had one cumulative confirmed case. The x-coordinate represents time (days) and the y-ordinate represents the
number of cumulative confirmed cases. The Guangdong government took “Seven Measures” (e.g. blockade of all schools and unnecessary public places) on the third day (Jan 21) to prevent the spread of the epidemic. There were only 241 cumulative confirmed cases on January 28 in Guangdong (Fig. 2B). In comparison, on February 28 Italy closed schools in Lombardy, the most serious epidemic area, when the number of cumulative confirmed cases was already 650 (Fig. 2A). This number is similar to the confirmed cases (i.e. 683) in Guangdong on February 2. Therefore, Italy closed schools about 5 days later than Guangdong. Guangdong’s prevention and control measures were more timely. The earlier the blockade is implemented, the more effective it is to control the epidemic. In Figure 2(D) we see that the newly confirmed cases in Guangdong began to decline since the 37th day and reached the peak of cumulative cases at 1347. However, the number of cumulative cases has already exceeded 10 thousands and newly reported cases are still ascending fast in Italy (Figure 2C). In summary, it took 14 days for Guangdong’s cases to decline since its cumulative confirmed cases exceeded 1000. How long it will take in Italy remains unclear. It highly depends on Italian current and future control strategies.

Data comparison in Italy and Guangdong

Italy has 60.48 million people while Guangdong has a population of 111.69 million. Thus, there are more susceptible people in Guangdong than in Italy. However, it can be seen from Figure 2(A) and (B) that it took 19 days for Guangdong Province to increase from 1 case to more than 1000 cases, while it took only 11 days for Italy to increase from 4 cases to more than 1000 cases. It illustrates that the prevention and control tactics of Guangdong Province in the early stage of the epidemic is more effective than that of Italy with the similar rate of diagnosis.

At present, the number of newly confirmed cases in Italy is still rising (shown in Figure 2C). The ascent and descent of newly confirmed cases are bound up with the prevalence ratio, cure ratio and prevention and control measures in the two places. When other conditions are the same, the higher the prevalence ratio, the higher the cure ratio. The more effective the interventions, the fewer newly diagnosed patients per day. Specifically, in Figure 3 we utilize the ratio of reported cases to the total population to represent the prevalence ratio. Because the calculated prevalence ratios are very small, we multiply by 10000 for the ease of illustration. Similarly, we use the ratio of recovered cases to cumulative confirmed population to represent the cure ratio. In sum, we select February 20 as Italy’s 1st day and February 19 as Guangdong’s 1st day, with the x-axis representing days and y-axis representing the prevalence ratio or cure ratio. Italian prevalence ratio is much higher than Guangdong’s (Figure 3A). Italy has more than 20 times as many patients as Guangdong, while Guangdong has nearly twice as many susceptible populations as Italy. This means that Italian epidemic state is far more serious than Guangdong’s. This really demands Italian authorities to issue more severe control actions to resolve this public health crisis.

In view of the cure ratio (Figure 3B), we can see that Guangdong’s curve is more smooth than Italy, which means that Guangdong’s cure ratio is more stable than Italy’s. This suggests that Guangdong has more sufficient medical resources than Italy. Medical resource definitely plays a critical role in reducing the mortality rate due to COVID-19.

The above three aspects of data observation and comparison suggest that the situation of the international epidemic, particularly in Italy, is urgent. Compared with Guangdong province, Italy implemented control measures less timely and effectively. Currently, Italian
epidemic is in a severe status. If the authorities do not take stronger control measures, Italy would face a more serious public health crisis. Last but not least, the cure ratio curve (Figure 3B) shows that there is deficiency in medical resource in Italy.

Model
To study the epidemic of COVID-19 spread in Italy, we extend the classical deterministic susceptible-exposed-infectious-removed (SEIR) epidemic model by dividing the population into susceptible (S), exposed (E), symptomatic/asymptomatic infected (IA), confirmed (H) and recovered (R) compartments. The susceptible and exposed populations are further partitioned into quarantined susceptible (Sq) and quarantined suspected individuals (Eq). This modeling framework is based on the previous research [21, 22]. The model is as follows:

\[
\begin{align*}
\frac{dS}{dt} & = -(\beta c + cq(1-\beta))S \frac{(I+\theta A)}{N} + \lambda S_q, \\
\frac{dE}{dt} & = \beta c(1-q)S \frac{(I+\theta A)}{N} - \sigma E, \\
\frac{dI}{dt} & = \sigma \rho E - (\delta I + \alpha + \gamma I)I, \\
\frac{dA}{dt} & = \sigma(1-\rho)E - \gamma A, \\
\frac{dS_q}{dt} & = (1-\beta)cqS \frac{(I+\theta A)}{N} - \lambda S_q, \\
\frac{dE_q}{dt} & = \beta cq S \frac{(I+\theta A)}{N} - \delta_q E_q, \\
\frac{dH}{dt} & = \delta I I + \delta_q E_q - (\alpha + \gamma H)H, \\
\frac{dR}{dt} & = \gamma I I + \gamma A A + \gamma H H.
\end{align*}
\]

The descriptions of the parameters are summarized in Table 1. In the early stage of the epidemic in Italy, the government of Italy did not take aggressive measures across the country. We use the reported number of cumulative confirmed cases, death cases and recovery cases from February 20th to March 10th (Figure 2) to estimate the parameters in model (1). The estimated values of all parameters relevant to the disease development are displayed in Table 1. Figure 4 shows a good fit to the data in Italy. As the population size is much larger than the size of the outbreak, i.e. \( S(t)/N \approx 1 \), the basic reproductive number \( R_0 \) of model (1) is given by the following formula

\[
R_0 = \frac{\beta \rho c (1-q)}{\delta I + \alpha + \gamma I} + \frac{\beta (1-\rho) c \theta (1-q)}{\gamma A}.
\]

According to the estimated values of parameters, the values of \( R_0 \) is 4.3211. The basic reproduction number is the average number of secondary infections produced by a typical case of an infection in a wholly susceptible population. It suggests that the transmission potential of COVID-19 is great in Italy.

Results
The number of COVID-19 confirmed cases in Italy was increasing rapidly in late February and early March. On March 8th, 2020, most places of northern Italy including Lombardia and Modena, the worst-hit regions in Italy, were categorized as the block zone where strict travel restrictions were implemented for controlling the infection. Immediately following the announcement, the whole country was locked down on March 10th, 2020. In mathematical modeling, these actions can reduce the contact rate \( c \) among people. In this study,
we assume that the contact rate is a decreasing function of time $t$ after the government has taken control measures. The contact rate $c(t)$ is assumed to take the following form:

$$c(t) = \begin{cases} 
    c_0, & t \leq t^*, \\
    (c_0 - c_b)e^{-r_1(t-t^*)} + c_b, & t > t^*.
\end{cases} \tag{2}$$

Here $c_0$ denotes the contact rate at the initial time without control measures, $c_b$ denotes the minimum contact rate under the current control strategies ($c_b < c_0$). The parameter $r_1$ determines how fast the contact rate decreases under control measures. The data we used for fitting started from February 11, 2020 and the country of Italy was blockaded on March 10, 2020. Thus, we let $t^* = 20$.

Another key factor in the development of the epidemic is the diagnosis rate $\delta_I(t)$. This parameter can be affected by many factors, such as the efficiency of detection and availability of medical resources. We assume that the duration of diagnosis $1/\delta_I(t)$ is given by the following form:

$$\frac{1}{\delta_I(t)} = \begin{cases} 
    \frac{1}{\delta_{I_0}}, & t \leq t^*, \\
    \left(\frac{1}{\delta_{I_0}} - \frac{1}{\delta_{I_f}}\right)e^{-r_2(t-t^*)} + \frac{1}{\delta_{I_f}}, & t > t^*.
\end{cases} \tag{3}$$

where $\delta_{I_0}$ is the diagnosis rate at the initial time. If the efficiency of detection is increasing with time $t$, then the diagnosis rate $\delta_I(t)$ will increase. The parameter $r_2$ measures how fast the diagnosis rate increases (i.e. the duration of diagnosis decreases) as more medical equipments or resources become available. The final diagnosis rate $\delta_{I_f}$ is usually larger than $\delta_{I_0}$. However, if the medical resource is inadequate, the diagnosis rate $\delta_I(t)$ can decrease and the final diagnosis rate $\delta_{I_f}$ can be less than $\delta_{I_0}$.

The public awareness of prevention is also a key factor in controlling the spread of the disease. The media news coverage can provide a major source of information that may result in behavior changes, e.g. wearing facial masks and washing hands. In this study, the effect of media coverage on the infection is described by changing the transmission rate $\beta$. We assume that the transmission rate $\beta(t)$ can be affected by the number of reported confirmed cases $H(t)$. As the number of reported confirmed cases increases, the public will increase self-protection measures. We assume that the function of the transmission rate $\beta(t)$ takes the following form:

$$\beta(t) = \begin{cases} 
    \beta_0, & \text{if } \frac{1}{\log(H(t))} > 1, \\
    \beta_0 \frac{1}{\log(H(t))}, & \text{else}.
\end{cases} \tag{4}$$

where $k$ represents the strength of people’s awareness of prevention. The larger the value of $k$, the smaller the transmission rate.

With the above-mentioned interventions, the effective transmission potential is measured by the effective reproductive number $R_c(t)$. It is time-varying as the intervention measures vary over time. Due to the change of the contact rate, the diagnosis rate, the transmission rate, and the reproductive number all change over time $t$. If $R_c(t)$ declines to less than 1, the number of infected cases will decline eventually.

Based on the parameter estimates, we analyze the progression of the disease outbreak under different control intensities. In Figures 5 and 6, we study the variation in the epidemic by changing parameters related to the contact rate and diagnosis rate including $c_b$, $r_1$, $\delta_{I_f}$,
Figures 5 and 6 show changes of the disease dynamics when the diagnosis rate \( \delta_I(t) \) is an increasing function and a decreasing function, respectively. There are in total 24 sets of parameter values, representing the variation in the intensity of the control measures implemented. The x-axis in Figures 5 and 6 is the time from February 20th. When \( \delta_I(t) \) increases over time \( t \), i.e. \( \delta_{I_0} < \delta_I(t) \), figures of the same color in Figure 5(A), (C) and (E) show that improving the efficiency of infection detection can largely affect the spread of the infection. The simulations with four different colors in Figure 5(A), (C) and (E) show that when the exponential decreasing rate in the contact rate increases, the number of confirmed cases will decrease and the epidemic will peak earlier. Thus, a lower contact rate will better control the disease outbreak. In addition, the effective reproduction number \( R(t) \) will decrease eventually to less than 1 as the control intensities increase, see Figure 5(B), (D) and (F). Therefore, the stronger the control intensity, the faster the infection goes extinct.

During the outbreak of COVID-19, the number of infections rises, leading to the shortage of medical resources. The detection rate may not rise. We use \( \delta_{I_0} \leq \delta_I(t) \) to describe this situation in which \( \delta_I(t) \) decreases. The magenta and green curves in Figure 6 (A), (C) and (E) show that the maximum level of the infection will increase when the minimum diagnosis rate is 0.18 or 0.17. If the minimum diagnosis rate is 0.2 or the diagnosis rate does not increase, the blue and red curves in Figure 6 (A), (C) and (E) show that the number of confirmed cases is much higher than that in Figure 5. The predicted results of the time when the infection reaches the peak and the maximum number of confirmed cases under different parameter sets are shown in Table 2. These simulations illustrate the effects of prevention and control strategies on the disease control.

In Figure 7, we evaluate population’s response to the outbreak at four different levels by setting \( k = 1/8, 1/6, 1/5 \) in equation (4) and \( \beta(t) = \beta_0 \). The values of other parameters are the same as those in Table 1. The red curve shows that the cumulative confirmed cases will keep rising. Increasing the parameter \( k \) will reduce the number of cumulative confirmed cases and can be very effective in slowing the overall disease progression trend. Thus, media news coverage on the status of disease helps improve people’s awareness, leading to a better control of the disease outbreak.

**Discussion**

The COVID-19 transmission has become a global pandemic, creating unprecedented public health challenges in the world. On the basis of the latest data of COVID-19 cases, we compared the disease spread in Guangdong, a province of China and Italy. Data observation and analysis suggest that the prevention and control measures implemented in Italy were not sufficiently timely and effective. Italy closed schools at least five days later than Guangdong and the prevalence ratio in Italy is more than 20 times as Guangdong although Italy has fewer susceptible people. There are signs that the epidemic in Italy is far more serious than our prediction. This requires Italian government to make adjustment on the control measures. Moreover, the cure ratio curve reveals that there is also a shortage of medical equipments and resources in Italy.

Using the newest control measures implemented in Italy, we developed a deterministic model to study the transmission of COVID-19 in the early stage. Because there were no many prevention actions in the beginning, we estimated the basic reproduction number to be 4.3211. Considering that the Italian government issued national lockdown on March
10 and will continue taking actions such as restricting travel, providing more medical resources and improving media publicity, we use a time-dependent dynamic model to study the future disease dynamics in Italy. With effective measures the contact rate between people will gradually decrease and the diagnosis rate will increase. However, when the country’s medical resource goes exhausted, the diagnosis rate may decline. We incorporated all these possible scenarios into the model and performed numerical simulations, which are shown in Figures 5 and 6.

From Table 2, we considered a scenario in which very strict interventions are taken. We assumed that the minimum contact rate $c_b$ is 1 with the exponential decreasing rate $r_1 = 0.5$ and the fast diagnosis rate $\delta_{ff} = 0.5$ with the exponential increasing rate $r_2 = 0.5$ (i.e. the test result will be available in two days). In this scenario, Italy will reach the peak (i.e. 23900) after 43 days. However, based on previous data observation and analysis, Italy didn’t take timely and effective interventions in the beginning. Thus, the cumulative reported cases have already exceeded 26300. Social media was also shown to have a substantial impact on controlling the transmission. More media coverage on the outbreak leads to more self-protection, resulting in less infection (Figure 7).

At present, the number of newly diagnosed patients in China has reached 0. The disease has been effectively controlled. However, in Europe the number of new infections is still rising. We used mathematical models and numerical simulations to evaluate the effects of control measures. The results show that people’s self-quarantine is an useful measure to reduce exposure. The diagnosis rate is also an important parameter. If the diagnosis rate increases, then the disease will peak earlier and the peak value is also lower. It is worth noting that if the diagnosis rate drops due to limited medical resources, then Italy won’t be able to take effective actions such as "early detection, early isolation and early treatment", "forced isolation for certain people" and "timely treatment for patients", which were shown to be effective in mitigate the epidemic in China. In view of these data fitting and model prediction, international mutual assistance such as providing more personal protective equipments would be needed to combat this global catastrophic pandemic caused by both the virus and the shortage of medical resources during the outbreak.

**Conclusion**

In summary, this work studies the current epidemic status in Italy and assesses its control interventions from data observation, mathematical modelling and analysis. Italy is currently in a very serious epidemic situation since control measures such as quarantine, blockade of schools and medical support are not sufficiently timely and effective. It is recommended that Italy and other countries in the similar epidemic status enforce severer isolation and blockade orders, strengthen the supplement of medical resources, and reinforce international cooperation and mutual assistance.

**Ethical Approval and Consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Availability of supporting data**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.
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Author’s contributions
Conceptualization: S.T.; methodology: S.T. and L.R.; software: S.H. and P.L.; validation: S.H. and P.L.; formal analysis: P.L. and S.H.; investigation: P.L. and S.H.; data curation: P.L. and S.H.; writing (original draft preparation): P.L. and S.H.; writing (review and editing): L.R.; visualization: L.R.; supervision: L.R. and S.T.; project administration: S.T. and L.R.; funding acquisition: S.T., L.R and S.H. All authors have read and agreed to the published version of the manuscript.

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Figures

**Figure 1** The epidemics in Europe and the world. The red bar represents the number of countries with confirmed cases in the world. The yellow bar represents the number of countries with confirmed cases in Europe.

Tables
Figure 2 Cumulative reported cases, control measures and newly confirmed cases in Italy and Guangdong. (A): Cumulative reported cases in Italy. A1 is Feb 28 when Lombardy’s University was closed until March 7. A2 is Mar 9 when Italy announced that all schools were closed until April 3. A3 is March 10 when Italy locked down the whole country. (B): Cumulative reported cases in Guangdong. B1 is Jan 1 when Guangdong announced “Seven Measures” to mitigate the epidemic. B2 is Jan 28 when Guangdong closed all schools until the end of February. (C): Newly confirmed cases in Italy. (D): Newly confirmed cases in Guangdong.

Figure 3 The prevalence ratio (A) and cure ratio (B) in Italy and Guangdong.

Figure 4 Data fitting to cumulative confirmed cases (A), death cases (B), and recovered cases (C).

Figure 5 The prediction of cumulative cases (left column) and the effective reproduction number (right column) with different sets of parameter values (see text).

Figure 6 The prediction of cumulative cases (left column) and the effective reproduction number (right column) with different sets of parameter values (see text).

Figure 7 The prediction of cumulative cases with different transmission rates.

Table 1 Estimates of parameters and initial values of variables in model (1).

| Parameters | Definition                                                                 | value          | Source   |
|------------|---------------------------------------------------------------------------|----------------|----------|
| $c$        | Initial contact rate                                                      | 15 estimated   |          |
| $\beta$    | Probability of successful transmission                                    | 0.1334         | estimated|
| $\theta$   | Transmission probability reduction of asymptomatically infected individuals | 0.1            | estimated|
| $\rho$     | Ratio of symptomatic infection                                            | 0.6            | estimated|
| $q$        | Quarantine rate of exposed individuals                                    | 0.415          | estimated|
| $\sigma$   | Transition rate of exposed individuals to the infected class              | 1/17           |          |
| $\lambda$  | Rate at which the quarantined uninfected contacts are released             | 1/14           | [21]     |
| $\delta_t$ | Transition rate of symptomatically infected individuals to the quarantined infected class | 0.2257         | estimated|
| $\delta_q$ | Transition rate of quarantined exposed individuals to the quarantined infected class | 0.2            | estimated|
| $\gamma_t$ | Recovery rate of symptomatically infected individuals                     | 0.02           | estimated|
| $\gamma_A$ | Recovery rate of asymptomatically infected individuals                    | 0.07           | estimated|
| $\gamma_H$ | Recovery rate of quarantined infected individuals                        | 0.0239         | estimated|
| $\alpha$   | Disease-induced death rate                                                | 0.013          | estimated|
| $N$        | The total population                                                      | $6.048 \times 10^7$ | Data |
| $E(0)$     | Initial exposed population                                                | 26 estimated   |          |
| $I(0)$     | Initial symptomatically infected population                               | 20 estimated   |          |
| $A(0)$     | Initial asymptomatically infected population                              | 5 estimated    |          |
| $S_q(0)$   | Initial quarantined susceptible population                                | 51 estimated   |          |
| $E_q(0)$   | Initial quarantined exposed population                                    | 13 estimated   |          |
| $H(0)$     | Initial quarantined infected population                                   | 41 Data        |          |
| $R(0)$     | Initial recovered population                                              | 6 Data         |          |
Table 2 Different control measure intensities and prediction results

| Parameter assumption | Peak day | Maximum confirmed cases |
|----------------------|----------|-------------------------|
| $c_b = 4, r_1 = 0.03$ |          |                         |
| $\delta_{I_f} = 0.5, r_2 = 0.05$ | 79       | $1.54 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.1$ | 76       | $1.08 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.5$ | 76       | $1.03 \times 10^4$     |
| $\delta_{I_f} = \delta_{I_0} r_2 = 0.05$ | 144      | $3.36 \times 10^4$     |
| $\delta_{I_f} = 0.2 r_2 = 0.05$ | 181      | $8.34 \times 10^4$     |
| $c_b = 4, r_1 = 0.05$ |          |                         |
| $\delta_{I_f} = 0.5, r_2 = 0.05$ | 60       | $5.85 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.1$ | 57       | $4.81 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.5$ | 56       | $4.49 \times 10^4$     |
| $\delta_{I_f} = \delta_{I_0} r_2 = 0.05$ | 101      | $2.96 \times 10^4$     |
| $\delta_{I_f} = 0.2 r_2 = 0.05$ | 127      | $5.11 \times 10^4$     |
| $c_b = 4, r_1 = 0.1$ |          |                         |
| $\delta_{I_f} = 0.5, r_2 = 0.05$ | 48       | $3.12 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.1$ | 46       | $2.85 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.5$ | 46       | $2.75 \times 10^4$     |
| $\delta_{I_f} = \delta_{I_0} r_2 = 0.05$ | 66       | $5.32 \times 10^4$     |
| $\delta_{I_f} = 0.2 r_2 = 0.05$ | 63       | $6.78 \times 10^4$     |
| $c_b = 1, r_1 = 0.5$ |          |                         |
| $\delta_{I_f} = 0.5, r_2 = 0.05$ | 46       | $2.61 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.1$ | 44       | $2.45 \times 10^4$     |
| $\delta_{I_f} = 0.5 r_2 = 0.5$ | 43       | $2.39 \times 10^4$     |